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A sensorimotor account of vision and visual consciousness

J. Kevin O'Regan
Laboratoire de Psychologie Expérimentale, Centre National de Recherche Scientifique, Université René Descartes, 92774 Boulogne Billancourt, France
oregan@ext.jussieu.fr http://nivea.psycho.univ-paris5.fr

Alva Noë
Department of Philosophy, University of California at Santa Cruz, Santa Cruz, CA 95064
anoe@cats.ucsc.edu http://www2.ucsc.edu/people/anoe/

Abstract: Many current neurophysiological, psychophysical, and psychological approaches to vision rest on the idea that when we see, the brain produces an internal representation of the world. The activation of this internal representation is assumed to give rise to the experience of seeing. The problem with this kind of approach is that it leaves unexplained how the existence of such a detailed internal representation might produce visual consciousness. An alternative proposal is made here. We propose that seeing is a way of acting. It is a particular way of exploring the environment. Activity in internal representations does not generate the experience of seeing. The outside world serves as its own, external, representation. The experience of seeing occurs when the organism masters what we call the governing laws of sensorimotor contingency. The advantage of this approach is that it provides a natural and principled way of accounting for visual consciousness, and for the differences in the perceived quality of sensory experience in the different sensory modalities. Several lines of empirical evidence are brought forward in support of the theory, in particular: evidence from experiments in sensorimotor adaptation, visual "filling in," visual stability despite eye movements, change blindness, sensory substitution, and color perception.

Keywords: action; change blindness; consciousness; experience; perception; qualia; sensation; sensorimotor

1. Introduction

1.1. The puzzle of visual experience

What is visual experience and where does it occur?

It is generally thought that somewhere in the brain an internal representation of the outside world must be set up which, when it is activated, gives us the experience that we all share of the rich, three-dimensional, colorful world. Cortical maps – those cortical areas where visual information seems to be retinotopically organized – might appear to be good candidates for the locus of perception.

Cortical maps undoubtedly exist, and they contain information about the visual world. But the presence of these maps and the retinotopic nature of their organization cannot *in itself* explain the metric quality of visual phenomenology. Nor can it explain why activation of cortical maps should produce visual experience. Something extra would appear to be needed in order to make excitation in cortical maps provide, in addition, the subjective impression of seeing.

A number of proposals have come forth in recent years to suggest how this might come about. For example, it has been suggested, from work with blindsight patients, that consciousness in vision may derive from a "commentary" system situated somewhere in the fronto-limbic complex (taken to include the prefrontal cortex, insula and claustrum; cf. Weiskrantz 1997, p. 226). Crick and Koch (1990),

KEVIN O'REGAN moved to Paris in 1975 after studying theoretical physics in England, to work in experimental psychology at the Centre National de Recherche Scientifique. After his Ph.D. on eye movements in reading he showed the existence of an optimal position for the eye to fixate in words. His interest in the problem of the perceived stability of the visual world led him to question established notions of the nature of visual perception, and to recently discover, with collaborators, the phenomenon of "change blindness." His current work involves exploring the empirical consequences of the new approach to vision.

ALVA NOË is a philosopher at the University of California, Santa Cruz. He received a Ph.D. in philosophy from Harvard University and a B. Phil. from Oxford University, and he has been a Research Associate of the Center for Cognitive Studies at Tufts University. He has published articles on topics in the philosophy of perception, philosophy of mind, and other areas, including a previous *Behavioral and Brain Sciences* target article on perceptual completion. He is currently at work on a book on the relation between perception and action, and he is a co-editor of *Vision and Mind: Selected Readings in the Philosophy of Perception* (MIT Press, forthcoming).

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Llinas and Ribary (1993), Singer (1993), and Singer and Gray (1995) suggest that consciousness might be correlated with particular states of the brain involving coherent oscillations in the 40–70 Hz range, which would serve to bind together the percepts pertaining to a particular conscious moment.[1] Penrose (1994) and Hameroff (1994) suggest that the locus of consciousness might be a quantum process in neurons' microtubules. Edelman (1989) holds that reentrant signaling between cortical maps might give rise to consciousness. A variety of other possibilities that might constitute the "neural correlate of consciousness" has been compiled by Chalmers (1996b).

A problem with proposals of this kind is that they do little to elucidate the mystery of visual consciousness (as pointed out by, for example, Chalmers 1996b). For even if one particular mechanism – for example, coherent oscillations in a particular brain area – were proven to correlate perfectly with behavioral measures of consciousness, the problem of consciousness would simply be pushed back into a deeper hiding place: the question would now become, why and how should coherent oscillations ever generate consciousness? After all, coherent oscillations are observed in many other branches of science, where they do not generate consciousness. And even if consciousness is assumed to arise from some new, previously unknown mechanism, such as quantum-gravity processes in tubules, the puzzle still remains as to what exactly it is about tubules that allows them to generate consciousness, when other physical mechanisms do not.

1.2. What are sensory modalities?

In addition to the problem of the *origin* of experience discussed in the preceding paragraphs, there is the problem of *differences* in the felt quality of visual experience. Why is the experience of red more like the experience of pink than it is like that of black? And, more generally, why is seeing red very different from hearing a sound or smelling a smell?

It is tempting to think that seeing red is like seeing pink because the neural stimulation going on when we see something red is similar to that underlying our perception of pink: almost the same ratios of long, medium and short wavelength photoreceptors will be stimulated by red and pink. But note that though this seems reasonable, it does not suffice: there is no *a priori* reason why similar neural processes should generate similar percepts.[2] If neural activity is just an arbitrary code, then an explanation is needed for the particular sensory experience that will be associated with each element of the code. Why, for example, should more intense neural activity provoke more intense experiences? And what exactly is the mapping function: is it linear, logarithmic, or a power function? And why is it one of these rather than another? Even these questions leave open the more fundamental question of how a neural code could ever give rise to experience at all.

Not very much scientific investigation has addressed this kind of question. Most scientists seem satisfied with some variant of Müller's (1838) classic concept of "specific nerve energy." Müller's idea, in its modern form,[3] amounts to the claim that what determines the particularly visual aspect of visual sensations is the fact that these sensations are transmitted by specific nerve pathways (namely, those originating in the retina and not in the cochlea) that project to particular cerebral regions (essentially, cortical area V1). It is certainly true that retinal influx comes together in relatively circumscribed areas of the brain, and that this may provide an architectural advantage in the neural implementation of the calculations necessary to generate visual-type sensations. But what is it about these pathways that generates the different sensations? Surely the choice of a particular subset of neurons or particular cortical regions cannot, *in itself*, explain why we attribute visual rather than auditory qualities to this influx. We could suppose that the neurons involved are of a different kind, with, say, different neurotransmitters, but then why and how do different neurotransmitters give rise to different experiences? We could say that the type of calculation done in the different cortical areas is different, but then we must ask, how could calculations ever give rise to experience? The hard work is left undone. Much still needs to be explained.

1.3. An alternative approach: The sensorimotor contingency theory

The present paper seeks to overcome the difficulties described above by adopting a different approach to the problem of visual experience. Instead of assuming that vision consists in the creation of an internal representation of the outside world whose activation somehow generates visual experience, we propose to treat vision as an *exploratory activity*. We then examine what this activity actually consists in. The central idea of our new approach is that *vision is a mode of exploration of the world that is mediated by knowledge of what we call sensorimotor contingencies.* We show that problems about the nature of visual consciousness, the qualitative character of visual experience, and the difference between vision and other sensory modalities, can now, from the new standpoint, all be approached in a natural way, without appealing to mysterious or arcane explanatory devices.

2. The structure of vision

As stated above, we propose that *vision is a mode of exploration of the world that is mediated by knowledge, on the part of the perceiver, of what we call sensorimotor contingencies.* We now explore this claim in detail.

2.1. Sensorimotor contingencies induced by the visual apparatus

Imagine a team of engineers operating a remote-controlled underwater vessel exploring the remains of the Titanic, and imagine a villainous aquatic monster that has interfered with the control cable by mixing up the connections to and from the underwater cameras, sonar equipment, robot arms, actuators, and sensors. What appears on the many screens, lights, and dials, no longer makes any sense, and the actuators no longer have their usual functions. What can the engineers do to save the situation? By observing the *structure of the changes* on the control panel that occur when they press various buttons and levers, the engineers should be able to deduce which buttons control which kind of motion of the vehicle, and which lights correspond to information deriving from the sensors mounted outside the vessel, which indicators correspond to sensors on the vessel's tentacles, and so on.

There is an analogy to be drawn between this example and the situation faced by the brain. From the point of view of the brain, there is nothing that in itself differentiates nervous influx coming from retinal, haptic, proprioceptive, olfactory, and other senses, and there is nothing to discriminate motor neurons that are connected to extraocular muscles, skeletal muscles, or any other structures. Even if the size, the shape, the firing patterns, or the places where the neurons are localized in the cortex differ, this does not in itself confer them with any particular visual, olfactory, motor or other perceptual quality.

On the other hand, what *does* differentiate vision from, say, audition or touch, is the *structure of the rules* governing the sensory changes produced by various motor actions, that is, what we call the *sensorimotor contingencies* governing visual exploration. Because the sensorimotor contingencies within different sensory domains (vision, audition, smell, etc.) are subject to different (in)variance properties, the structure of the rules that govern perception in these different modalities will be different in each modality.

A first law distinguishing visual percepts from perception in other modalities is the fact that when the eyes rotate, the sensory stimulation on the retina shifts and distorts in a very particular way, determined by the size of the eye movement, the spherical shape of the retina, and the nature of the ocular optics. In particular, as the eye moves, contours shift and the curvature of lines changes. For example, as shown in Figure 1, if you are looking at the midpoint of a horizontal line, the line will trace out a great arc on the inside of your eyeball. If you now switch your fixation point upwards, the curvature of the line will change; represented on a flattened-out retina, the line would now be curved. In general, straight lines on the retina distort dramatically as the eyes move, somewhat like an image in a distorting mirror.

Similarly, because of the difference in sampling density of the retinal photoreceptors in central and in peripheral vision, the distribution of information sensed by the retina changes drastically, but in a lawful way, as the eye moves. When the line is looked at directly, the cortical representation of the straight line is fat in the middle and tapers off to the ends. But when the eye moves off the line, the cortical representation peters out into a meager, banana-like shape, and the information about color is radically undersampled, as shown in the bottom right hand panel of Figure 1. Another law that characterizes the sensorimotor contingencies that are particular to visual percepts is the fact that the flow pattern on the retina is an expanding flow when the body moves forwards, and contracting when the body moves backwards. Visual percepts also share the fact that when the eyes close during blinks, the stimulation changes drastically, becoming uniform (i.e., the retinal image goes blank).

In contrast to all these typically *visual* sensorimotor contingencies, *auditory* sensorimotor contingencies have a different structure They are not, for example, affected by eye movements or blinks. They are affected in special ways by head movements: rotations of the head generally change the temporal asynchrony between left and right ears. Movement of the head in the direction of the sound source mainly affects the amplitude but not the frequency of the sensory input.

We therefore suggest that a crucial fact about vision is that visual exploration obeys certain laws of sensorimotor contingency. These laws are determined by the fact that the exploration is being done by the visual apparatus.

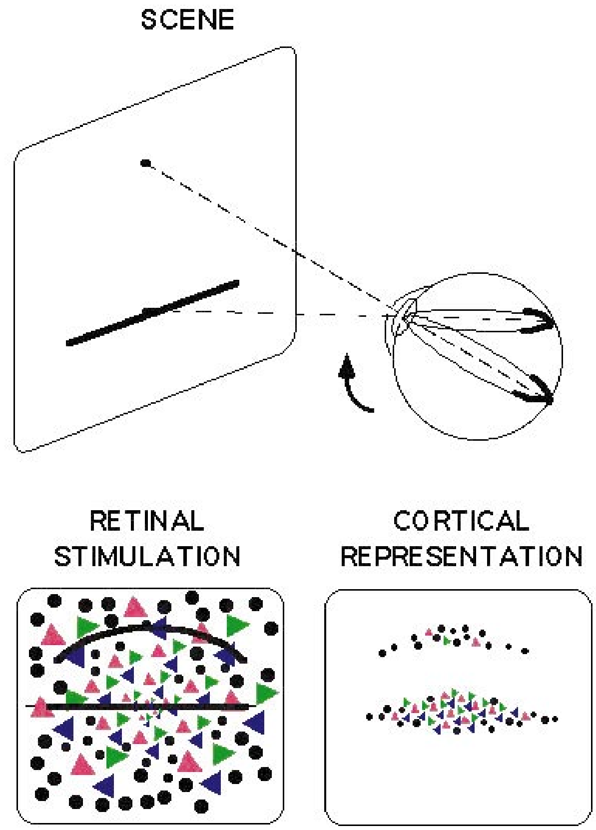

Figure 1. **Top:** The eye fixates the middle of a straight line and then moves to a point above the line. The retinal stimulation moves from a great arc on the equator of the eye to a different, smaller great arc. **Bottom left**: Flattened out retina showing great arc corresponding to equator (straight line) and off-equator great arc (curved line). Triangles symbolize color-sensitive cone photoreceptors, discs represent rod photoreceptors. Size of photoreceptors increases with eccentricity from the center of the retina. **Bottom right**: Cortical activation corresponding to stimulation by the two lines, showing how activation corresponding to a directly fixated straight line (large central oblong packet tapering off towards its ends) distorts into a thinner, banana shaped region, sampled mainly by rods, when the eye moves upwards. As explained in Section 2.2, if the eye moves *along* the straight line instead of upwards, there would be virtually *no change at all* in the cortical representation. This would be true even if the cortical representation were completely scrambled. This is the idea underlying the theory that shape in the world can be sensed by the laws obeyed by sensorimotor contingencies.

In summary: the sensorimotor contingencies discussed in this section are related to the visual apparatus and to the way three-dimensional objects present themselves to the visual apparatus. These sensorimotor contingencies are distinctive of the visual sense modality, and differ from the sensorimotor contingencies associated with other senses.

2.2. Sensorimotor contingencies determined by visual attributes

Real objects have properties such as size, shape, texture, and color, and they can be positioned in the three-dimensional world at different distances and angles with respect to an observer. Visual exploration provides ways of sampling these properties which differs from sampling via other senses. What characterizes the *visual* mode of sampling object properties are such facts as that the retinal image of an object only provides a view of the front of an object, and that when we move around it, parts appear and disappear from view; and that we can only apprehend an object from a definite distance, so that its retinal projection has a certain size that depends on distance. Other characteristics of visual exploration of objects derive from the fact that color and brightness of the light reflected from an object change in lawful ways as the object or the light source or the observer move around, or as the characteristics of the ambient light change.

On the other hand, tactile exploration of an object, even though it may be sampling the same objective properties, obeys different sensorimotor contingencies: you do not touch an object from a "point of view" – your hand can often encompass it more or less completely for example, and you don't apprehend it from different distances; its tactile aspect does not change with lighting conditions.

There is thus a subset of the sensorimotor contingencies that are engendered by the constraints of visual-type exploration, and which corresponds to *visual* attributes of sensed objects.

Note that unlike the sensorimotor contingencies that are visual-modality related, the sensorimotor contingencies that are visual-attribute related do, nonetheless, have strong links to the tactile sense: this is because attributes of three dimensional objects can also sometimes be apprehended via the tactile exploratory mode, where they present themselves as tactile shape, texture, size, distance. As shown eloquently by Piaget's work, the observer's conception of space in general will also have strong links to the laws of sensorimotor contingency discussed in the present section. Similar ideas were developed by Poincaré who wrote:

> To localize an object simply means to represent to oneself the movements that would be necessary to reach it. It is not a question of representing the movements themselves in space, but solely of representing to oneself the muscular sensations which accompany these movements and which do not presuppose the existence of space. (Poincaré 1905, p. 47)

A good illustration of sensorimotor contingencies associated with one particular kind of visual attribute, namely, visual shape, can be obtained from the records of patients whose vision has been restored after having been born blind with congenital cataract (cf. reviews by Gregory 1973; Jeannerod 1975; Morgan 1977). One such patient, cited by Helmholtz (1909/1925), is surprised that a coin, which is round, should so drastically change its shape when it is rotated (becoming elliptical in projection). The fact that objects also drastically change in extent as a function of distance is poignantly illustrated by the case of a 13–14 year old boy treated by Cheseldon (1728; cited by Morgan 1977, p. 20):

> Being shewn his father's picture in a locket at his mother's watch, and told what it was, he acknowledged a likeness, but was vastly surpriz'd; asking, how it could be, that a large face could be express'd in so little room, saying, it should have seem'd as impossible to him, as to put a bushel of any thing into a pint.

These examples make us realize how second nature it is for people with normal vision to witness the perspective changes that surfaces undergo when they are shifted or tilted, or when we move with respect to them. The idea we wish to suggest here is that the visual quality of shape *is precisely* the set of all potential distortions that the shape undergoes when it is moved relative to us, or when we move relative to it. Although this is an infinite set, the brain can abstract from this set a series of laws, and it is this set of laws which codes shape.[4]

Another example of how sensorimotor contingencies can be used as indicators of visual attributes is illustrated in an aspect of Figure 1 we have not yet mentioned. We saw in the introduction that movement of the eye away from a line creates a very strong distortion in its cortical and retinal representation. Under the classical view of what shape perception requires, it would be necessary to postulate that in order to see lines as straight despite eye movements, a transformation mechanism would have to exist that compensates for these distortions. This mechanism would take the cortical representation illustrated in the bottom right of the figure, and transform it so the two dissimilar packets of stimulated neurons shown in the figure now look identical.[5] There would additionally have to be another cortical locus where this new, corrected representation was projected. The view presented here does away with these unnecessary steps.

Consider the following fact: if the eye moves *along* the straight line instead of perpendicular to it, the set of photoreceptors on the retina which are stimulated does not change, since each photoreceptor that was on the image of the line before the eye moves is still on the image after the eye moves. This is due to an essential property of lines – they are self-similar under translation along their length (we assume, for simplicity, that the line is infinite in length). Since exactly the same photoreceptors are being stimulated before and after eye movement along the line's length, the cortical representation of the straight line is therefore identical after such a movement: there is this time no distortion at all. Another interesting fact is that the argument we have just made is totally independent of the code used by the brain to represent the straight line. Even if the optic nerve had been scrambled arbitrarily, or if the retina were corrugated instead of spherical, thereby causing the image of the line to be wiggly instead of straight, or if the eye's optics gave rise to horrendous distortions, movement of the eye along the line would still not change the pattern of cortical stimulation. We see that this particular law of sensorimotor invariance is therefore an intrinsic property of straight lines, and is independent of the code used to represent them. Platt (1960) has extended such considerations to other geometrical invariants, and Koenderink (1984a) has considered the more general, but related problem of how spatiotemporal contingencies in the neural input can be used to deduce intrinsic geometrical properties independently of the code by which they are represented.

In general, it will be the case that the *structure of the laws* abstracted from the sensorimotor contingencies associated with flat, concave, and convex surfaces, corners, and so on, will be a neural-code-independent indication of their different natures. In relation to this, some psychophysical work is being done; for example, to determine the respective importance, in determining shape, of cues derived from changes caused by movement of the object versus movement of the observer (e.g., Cornilleau-Peres & Droulez 1994; Dijkstra et al. 1995; Rogers & Graham 1979; Rogers & Rogers 1992). Nonetheless, though it is inherent in the approaches of a number of researchers (cf. sect. 3.3), the idea that the laws of sensorimotor contingency might actually *constitute* the way the brain codes visual attributes has not so far been greatly developed in the literature. However, this idea is essential in the present theory.

2.3. Sensation and perception

Psychologists interested in perception have traditionally distinguished between sensation and perception. While it is difficult to make this distinction precise, perhaps its central point is to differentiate between the way the senses are affected by stimuli (sensation) and the results of categorization of objects and events in the environment (perception). It is worthwhile to note that our distinction between two different classes of sensorimotor contingency roughly corresponds to this distinction between sensation and perception. Sensorimotor contingencies of the first sort – those that are determined by the character of the visual apparatus itself – are independent of any categorization or interpretation of objects and can thus be considered to be a fundamental, underlying aspect of visual *sensation.* Sensorimotor contingencies of the second sort – those pertaining to visual attributes – are the basis of visual *perception.*

In this way we can interpret the present theory as attempting to do justice to one of the working doctrines of traditional visual theory.

2.4. Perceivers must have mastery of patterns of sensorimotor contingency

Consider a missile guidance system allowing a missile to home in on an enemy airplane. As the missile zigzags around to evade enemy fire, the image of the target airplane shifts in the missile's sights. If the missile turns left, then the image of the target shifts to the right. If the missile slows down, the size of the image of the airplane decreases in a predictable way. The missile guidance system must adequately interpret and adapt to such changes in order to track the target airplane efficiently. In other words, the missile guidance system is "tuned to" the sensorimotor contingencies that govern airplane tracking. It "knows all about" or "has mastery over" the possible input/output relationships that occur during airplane tracking.

Now consider what happens when the missile guidance system is out of order. The visual information is being sampled by its camera, it is getting into the system, being registered, but it is not being properly made use of. The missile guidance system no longer has mastery over airplane tracking.

We suggest that vision requires the satisfaction of two basic conditions. First, the animal must be exploring the environment in a manner that is governed by the two main kinds of sensorimotor contingencies (those fixed by the visual apparatus, and those fixed by the character of objects). Second, the animal, or its brain, must be "tuned to" these laws of sensorimotor contingencies. That is, the animal must be *actively exercising* its mastery of these laws.

Note that the notion of being tuned, or having mastery, only makes sense within the context of the behavior and purpose of the system or individual in its habitual setting. Consider again the missile guidance system. If exactly the same system was being used for a different purpose, say, for example, as an attraction in a fun fair, it might well be necessary for the system to have a different behavior, with scary lunges and strong acceleration and deceleration which would be avoided in a real system. Thus, "mastery" of the sensorimotor contingencies might now require a different set of laws.[6] In fact even the out-of-order missile guidance system has a kind of ineffectual mastery of its sensorimotor contingencies.

2.5. Important upshot: A sensory modality is a mode of exploration mediated by distinctive sensorimotor contingencies

The present view is able to provide an account of the nature and difference among sensory modalities. In the introduction we stressed the deficiencies of Müller's (1838) view as well as of its modern adaptation,[7] according to which it is supposed that what determines the differences between the senses is some inherent characteristic of the neural pathways that are involved: this view requires postulating some special extra property which differentiates the neural substrate of these pathways, or some special additional mechanism, whose nature then stands in need of further (and for now at least unavailable) explanation. The present approach obviates this difficulty by saying that what differentiates the senses are the *laws* obeyed by the sensorimotor contingencies associated with these senses.[8] Hearing and audition are both forms of exploratory activity, but each is governed by different laws of sensorimotor contingency. Just as it is not necessary to postulate an intrinsic "essence" of horseriding to explain why it feels different from motorcycling, it is similarly unnecessary to postulate a Müller-type specific nerve energy to account for the difference between vision and other senses.[9]

The sensory modalities, according to the present proposal, are constituted by distinct patterns of sensorimotor contingency. *Visual perception can now be understood as the activity of exploring the environment in ways mediated by knowledge of the relevant sensorimotor contingencies.* And to be a visual perceiver is, thus, to be capable of exercising mastery of vision-related rules of sensorimotor contingency.

We shall see that this approach, in which vision is considered to be a law-governed mode of encounter with the environment, opens up new ways of thinking about phenomena such as synesthesia, the facial vision of the blind, and, in particular, tactile visual sensory substitution, where apparently *visual* experience can be obtained through arrays of vibrators on the skin.

2.6. Visual awareness: Integrating sensorimotor contingencies with reasoning and action-guidance

Thus far we have considered two important aspects of vision: the distinctively *visual* qualities that are determined by the character of the sensorimotor contingencies set up by the visual apparatus; and the aspect which corresponds to the encounter with visual *attributes,* that is, those features which allow objects to be distinguished visually from one another. These two aspects go some way towards characterizing the qualitative nature of vision.

We now turn to a third important aspect of vision, namely, *visual awareness.*

Suppose you are driving your car and at the same time talking to a friend. As you talk, the vista in front of you is impinging upon your eyes. The sky is blue, the car ahead of you is red, there is oncoming traffic, and so on. Your brain is tuned to the sensorimotor contingencies related to these aspects of the visual scene. In addition, some of these sensorimotor contingencies are also being used to control your driving behavior, since you are continuously adjusting your steering and adapting your speed to the moment-to-moment changes in the road and the traffic. But, since you are talking to your friend, you do not attend to most of these things. You do not notice that the car ahead is red, you do not think about the sky being blue; you just drive and talk to your friend.

You lack, as we shall say, *visual awareness* of many of the aspects of the visual scene. For those scene aspects, you are no different from an automatic pilot controlling the flight of an airplane. Your behavior is regulated by the appropriate sensorimotor contingencies, but you remain visually unaware of the associated aspects of the scene.

But if you should turn your attention to the color of the car ahead of you, and think about it, or discuss it with your friend, or use the knowledge of the car's color to influence decisions you are making, then, we would say, you are aware of it. For a creature (or a machine for that matter) to possess visual awareness, what is required is that, in addition to exercising the mastery of the relevant sensorimotor contingencies, it must make use of this exercise for the purposes of thought and planning.[10]

When you not only visually track an environmental feature by exercising your knowledge of the relevant sensorimotor contingencies, but in addition integrate this exercise of mastery of sensorimotor contingencies with capacities for thought and action-guidance, then you are visually aware of the relevant feature. Then, we say, you *see* it.

Consider an important point about this view of what visual awareness is, namely that our possession of it is a *matter of degree.* In particular, in our view, all seeing involves some degree of awareness, and some degree of unawareness. For example, if you were to probe an *unaware* driver waiting at the light, there would probably be some aspects of the red light that were at least indirectly being integrated into the driver's current action-guidance, rational reflection and speech. Perhaps, though not noticing the light's *redness,* the *fact* that the light was red may make him realize that he was going to be late. Or, though not noting that the light was red, the driver could be noting that it was difficult to see because the sky was too bright. On the other hand, even the driver who was *aware* of seeing the red light may not have been aware of all its aspects, for example, that the shape of the light was different from usual. A visual stimulus has a very large (perhaps infinite) number of attributes, and only a small number can at any moment be influencing one's action-guidance, rational reflection, and speech behavior.

A further important fact about this account of visual awareness is that it treats awareness as something *non*magical. There is no need to suppose that awareness and seeing are produced by the admixture of some mysterious additional element. To see is to explore one's environment in a way that is mediated by one's mastery of sensorimotor contingencies, *and* to be making use of this mastery in one's planning, reasoning, and speech behavior.

2.7. Visual consciousness and experience: Forms of awareness

It may be argued that there is still something missing in the present account of vision, namely, an explanation of visual *consciousness,* or of the *phenomenal experience* of vision. Although there is a great deal of disagreement among philosophers about these notions, there is broad consensus, first, that seeing involves experience in the sense that there is something it is like to see, and second, that it is somehow mysterious how we can possibly explain this subjective character of experience, or, as it is sometimes put, the "raw feel" or the "qualia" of vision, in neural or other physical terms. Is there any reason to believe the sensorimotor contingency approach can succeed here where others have failed?

We will return to some of these issues in section 6 of this paper. For now, let us note that the present sensorimotor contingency framework would seem to allow for the explanation and clarification, and certainly, for the scientific study of a good deal of what makes for the subjective character of experience. Thus, one important dimension of what it is like to see is fixed by the fact that there is a lawful relation of dependence between visual stimulation and what we do, and this lawful relation is determined by the character of the visual apparatus. A second crucial feature that contributes to what it is like to see is the fact that objects, when explored visually, present themselves to us as provoking sensorimotor contingencies of certain typically visual kinds, corresponding to visual attributes such as color, shape, texture, size, hidden and visible parts. Together, these first two aspects of seeing, namely, the visual-apparatus-related sensorimotor contingencies and the visual-object-related sensorimotor contingencies, are what make vision *visual,* rather than, say, tactile or auditory. Once these two aspects are in place, the third aspect of seeing, namely, visual awareness, would seem to account *for just about all the rest* of what goes into making up the character of seeing. For, visual awareness is precisely the availability of the kinds of features and processes making up the first two aspects for the purposes of control, thought, and action.

As said, the question of visual experience and consciousness is extremely controversial, and we will defer further discussion of our view until section 6.

3. Refinements of the view

Vision, we argue, requires *knowledge* of sensorimotor contingencies. To avoid misunderstanding, it is necessary to discuss this claim in greater detail.

3.1. Knowledge of sensorimotor contingencies is a practical, not a propositional form of knowledge

Mastery of the structure of the rules is not something about which we (in general) possess propositional knowledge. For example, we are not able to describe all the changes that a convex surface should suffer, or the distortions that should occur, upon moving our eyes to all sorts of positions on the surface, or when we move or rotate it. Nevertheless, our brains have extracted such laws, and any deviation from the laws will cause the percept of the surface's shape to be modified. Thus, for example, our brains register the fact that the laws associated with normal seeing are not being obeyed when, for example, we put on a new pair of glasses with a different prescription: for a while, distortions are seen when the head moves (because eye movements provoke displacements of unusual amplitudes); or when we look into a fish tank (now moving the head produces unusual kinds of distortions), or dream or hallucinate (now blinking, for instance, has no effect). Our impression in such cases is that, then, something unusual is happening.

3.2. Mastery must be currently exercised

Another important condition that we need to impose for sensorimotor contingencies to properly characterize vision, is that the mastery of laws of sensorimotor contingency be exercised *now.* The reason we need this condition is the following.

Over the course of life, a person will have encountered myriad visual attributes and visual stimuli, and each of these will have particular sets of sensorimotor contingencies associated with it. Each such set will have been recorded and will be latent, potentially available for recall: the brain thus has mastery of all these sensorimotor sets. But when a particular attribute is currently being seen, then the particular sensorimotor contingencies associated with it are no longer latent, but are actualized, or being currently made use of. In the language of the missile guidance system: the system may have stored programs that are applicable to the task of following different kinds of planes with different speed and turning characteristics. All these programs are latent, and the system has mastery of them all. But it is only when the system is following a particular type of plane, that it invokes and follows the particular recipe for that plane.

Again: among all previously memorized action recipes that allow you to make lawful changes in sensory stimulation, only some are applicable at the present moment. The sets that are applicable *now* are characteristic of the visual attributes of the object you are looking at, and their being *currently exercised* constitutes the fact of your visually perceiving that object.

3.3. Historical note: Relation to other similar ideas

Consider the following analogy with haptic perception, suggested by MacKay (1962; 1967; 1973). Suppose you are a blind person holding a bottle with your hand. You have the feeling of holding a bottle, you feel the bottle. But what sensations do you really have? Without slight rubbing of the skin, tactile information is considerably reduced, and even temperature sensation will, through adaptation of the receptors, disappear after you have held the bottle for a while. In fact therefore, you may well have *very little* sensory stimulation coming from the bottle at the present instant. Yet, you actually have the feeling of "having a bottle in your hand" at this moment. This is because your brain is "tuned" to certain *potentialities:* if you were to slide your hand very slightly, a change would come about in the incoming sensory signals which is typical of the change associated with the smooth, sliding surface of glass. Furthermore, if you were to move your hand upwards, the size of what you are encompassing with your hand would diminish (because you are moving onto the bottle's neck), and if you were to move downwards, your tactile receptors would respond to the roughness coming from the transition from glass to the paper label.

MacKay suggests that *seeing* a bottle is an analogous state of affairs.[11] You have the impression of seeing a bottle if there is knowledge in your nervous system concerning a certain web of contingencies. For example, you have knowledge of the fact that if you move your eyes up towards the neck of the bottle, the sensory stimulation will change in a way typical of what happens when a narrower region of the bottle comes into foveal vision; you have knowledge expressing the fact that if you move your eyes downwards, the sensory stimulation will change in a way typical of what happens when the white label is fixated by central vision. Similarly, motions of an object created by manual manipulation can be part of what visually differentiates objects from one another. Unlike a bottle, an object like a pitcher with a handle can be rotated and the handle made to appear and disappear behind the body of the pitcher. It is the possibility of doing this which is indicative of the fact that this is a pitcher and not a bottle. The visual nature of pitchers involves the knowledge that there are things that can be done to them which make a protrusion (the handle) appear and disappear.

Ryle (1949/1990) has made similar points. He says of a person contemplating a thimble:

> Knowing how thimbles look, he is ready to anticipate, though he need not actually anticipate, how it will look, if he approaches it, or moves away from it; and when, without having executed any such anticipations, he does approach it, or move away from it, it looks as he was prepared for it to look. When the actual glimpses of it that he gets are got according to the thimble recipe, they satisfy his acquired expectation-propensities; and this is his espying the thimble. (p. 218)

Other authors have, over the last decades, expressed similar views. Hochberg (1968, p. 323), for example, in the context of his notion of schematic maps, refers to: "the program of possible samplings of an extended scene, and of contingent expectancies of what will be seen as a result of those samplings," and Sperry (1952) has the notion of "implicit preparation to respond." These ideas are also related to Neisser's (1976) perceptual cycle, to Noton and Stark's (1971) "scanpath" theory, and were also put forward in O'Regan (1992) in relation to the notion of the "world as an outside memory." Although, as noted by Wagemans and de Weert (1992), Gibson's notion of "affordance" (see Gibson 1982b; Kelso & Kay 1987; Turvey et al. 1981) is sometimes considered "mystical," it is undoubtedly strongly related to our present approach (on this, see Noë 2002). The importance of action in perception has been stressed by Paillard (1971; 1991) and Berthoz (1997). Similar notions have also been found useful in "active vision" robotics (Ballard et al. 1997; Brooks 1987; 1991). Thomas (1999), in an excellent review, has advocated an "active perception" approach to perception and visual imagery, which corresponds very closely to our second, object-related type of sensorimotor contingency.

Another related viewpoint is to be found in the work of Maturana and Varela (1987/1992). Maturana and Varela also emphasize the importance of sensorimotor coupling for understanding the structure of the animal's cognitive and perceptual capacities, as well as for understanding the organization of the nervous system. Varela et al. (1991) present an "enactive conception" of experience according to which experience is not something that occurs inside the animal, but is something the animal enacts as it explores the environment in which it is situated (see also Noë et al. 2000; Pessoa et al. 1998; Thompson 1995; Thompson et al. 1992). A related approach has been put forward by Järvilehto (1998a; 1998b; 1999; 2000), who, in a series of articles with an approach very similar to ours,[12] stresses that perception is activity of the whole organism-environment system.

All these views of what it is to see – particularly MacKay's and Ryle's, – are based on the same notion of sensorimotor contingency that is so central to the view we are proposing in the present article. MacKay's work, especially, was the main source of inspiration of our theory. However, it should be emphasized that our view contains several novel elements not to be found in the works of these authors.

The first point we have stressed is that there is an important distinction to be made between the two classes of sensorimotor contingencies, those which are particular to the visual apparatus, and those which are particular to the way objects occupy three-dimensional space and present themselves to the eye. Most of the researchers cited in the previous paragraphs have been concerned mainly with the sensorimotor contingencies associated with visual object attributes. An exception may be the case of Gibson, who considered the more apparatus-related sensorimotor contingencies in different terms. In any case, it seems to us that it is mainly, though not exclusively, through these latter contingencies that we can give a principled account of the qualitative differences in the *experienced phenomenology* of the different sensory modalities, thereby providing a more principled alternative to Müller's notion of "specific nerve energy."

A second innovative point in our approach will become more evident in section 6. We shall see that by taking the stance that the experience of vision is actually *constituted* by a mode of exploring the environment, we escape having to postulate magical mechanisms to instill experience into the brain.[13]

4. The world as an outside memory

4.1. The world as an outside memory

Under the present theory, visual experience does not arise because an internal representation of the world is activated in some brain area. On the contrary, visual experience is a mode of activity involving practical knowledge about currently possible behaviors and associated sensory consequences. Visual experience rests on know-how, the possession of skills.

Indeed, there is no "*re*"-presentation of the world inside the brain: the only pictorial or 3D version required is the real outside version. What *is* required, however, are methods for probing the outside world – and visual perception constitutes one mode via which it can be probed. The experience of seeing occurs when the outside world is being probed according to the visual mode, that is, when the knowledge being accumulated is of the three kinds described above, that are typical of the visual modality.

Thus, as argued in O'Regan (1992), it could be said that the outside world acts as an *external memory* that can be probed at will by the sensory apparatus.

To further clarify this, it is useful to make the relation with normal memory. You know many things about where you live. But as you sit in your office, you may not be thinking about them. If you should start doing so, you can conjure up in your mind all manner of things. Each thing can be thought about in detail, but meanwhile, the other things, though latent, are not being thought about. As you think about your kitchen, your bedroom is not in your mind, though you can cause it to come to mind by merely thinking about it. Remembering is casting one's awareness onto parts of latent memories.

Similarly, seeing is casting one's awareness onto aspects of the outside world made available by the visual apparatus. As you look at a visual scene, you can interrogate yourself about different aspects of the scene. As soon as you do so, each thing you ask yourself about springs into awareness, and is perceived – not because it enters into a cortical representation, but because knowledge is now available about how sensations will change when you move your eyes, or move the object. However, before you actually wonder about some aspect of the scene, although the information is "out there," and although you know you can obtain it by making the appropriate eye movement or attention shift, it is not currently available. It is not currently available for being visually "chewed upon" or "manipulated," and cannot at this moment be used to control judgments and utterances: the third, "awareness" aspect of seeing is missing. Thus, even though the image of the object is impinging upon your retina, and even if its aspects are being analyzed by the feature-extracting modules of your visual system, under the current theory of seeing we must say that the object is not actually being seen.

As will be described in section 5, this way of thinking about vision brings with it a number of consequences about some classic problems related to the apparent stability of the visual world despite eye movements, and to the problem of "filling-in" or compensating for "imperfections" of the visual apparatus such as the blind spot. It also provided the impetus for the change-blindness experiments described in section 5.10.

4.2. The impression of seeing everything

A rather counter-intuitive aspect of the world-as-outside-memory idea, and the associated notion that there is no picture-like internal representation of the outside world, is that, in a certain sense, only what is currently being processed is being "seen." How then, – if at any moment only a small fragment of the world is actually being seen, – could we ever have that strong subjective impression that we continually have of seeing "everything"?

As pointed out by Noë et al. (2000) and Noë (2001), this paradox is actually only apparent, and rests on a misunderstanding of what seeing really is. It is true that normal perceivers take themselves to be aware of a detailed environment. But what this means is that they perceive the environment surrounding them as detailed. It does not mean that they think that inside their brains there is a detailed copy of the environment. It is only those perceivers – and there are many scientists among them – who make the mistake of thinking that "seeing" consists of making such a copy, who are led to think there is a problem.

Another way of understanding why our visual phenomenology is of seeing everything in front of us, derives from the fact that since the slightest flick of the eye or attention allows any part of a visual scene to be processed at will, we have the feeling of immediate availability about the whole scene. In other words, despite the fact that we are only currently processing a small number of details of the scene, under the present definition of seeing, we really are seeing the *whole* scene.

Suppose you should ask yourself, "Am I currently consciously seeing *everything* there is to see in the scene?" How could you check that you were seeing everything? You would check by casting your attention on each element of the scene, and verify that you have the impression of consciously seeing it. But obviously as soon as you do cast your attention on something, you see it. Conclusion, you will always have the impression of consciously seeing everything, since everything you check on, you see. There is an interesting and unfortunate consequence of this: If for some reason you should not be able to mentally attend to some aspect of the scene, you will not be able to consciously see it. Some empirical examples of this are given in sections 5.10–5.12.

One could make the amusing analogy, referred to by Thomas (1999), of the refrigerator light. It seems to be always on. You open the refrigerator: it's on. You close the refrigerator, and then open it again to check, the light's still on. It seems like it's on all the time! Similarly, the visual field seems to be continually present, because the slightest flick of the eye, or of attention, renders it visible. Brooks (1991) has said that the world should be considered as its own best model, and Minsky (1988) has suggested the notion of "immanence illusion" in a similar vein.

4.3. Vividness through transients

In addition to the "slightest flick of attention" argument there is another, very important, factor which explains the particular vividness of the feeling we have of a rich external visual presence. The visual system is particularly sensitive to *visual transients* (Breitmeyer & Ganz 1976; Stelmach et al. 1984; Tolhurst 1975). When a visual transient occurs, an automatic, "alerting" or "attention-grabbing" mechanism appears to direct processing to the location[14] where the transient occurred (Theeuwes 1991; Yantis 1998). This means that should anything happen in the environment, we will generally consciously see it, since processing will be directed to it. This gives us the impression of "having tabs" on everything that might change, and so, of consciously seeing everything. Were there not the attention-grabbing mechanism, our visual impression would be more similar to the impression we have when we stand with our backs to a precipice: we keenly feel it is there, we know that we can turn and see more of the precipice, but the feeling of presence is much less vivid than when we are actually looking into the precipice. The knowledge of having tabs on any change that might occur in the visual field – the fact that we know any change will attract our attention, – is another thing that makes the "outside memory" providing vision different from other forms of memory. For, any change in the visual field is immediately visible to you; whereas if, say, a Latin noun drops out of your memory overnight, no whistle will blow to let you know!

4.4. Dreaming and mental imagery

It is often claimed that dreaming, or other types of mental imagery, provide a counterexample to our denial that the brain must represent what is seen. Since dreams and mental images are apparently pictorial in nature, this seems to show that we *are,* after all, capable of creating an internal iconic image. Penfield's classic observations (e.g., Penfield & Jasper 1954) of visual memories being created by stimulation of visual cortex might also be thought to indicate that there are internal pictorial representations.

It is easy to be misled by these arguments, which for some reason are peculiarly compelling. But it is important to appreciate that they are misleading. Whether dreams, hallucination, or normal vision are at stake, these arguments are another instance of the error of thinking that when we see things as picture-like (be it when we look at reality or when we have a dream), this must be because there is some kind of internal picture. But this is as misguided as the supposition that to see red, there must be red neurons in the brain. The supposed fact that things appear pictorial to us in no way requires there to be pictures in the head. Therefore, the fact that we dream, hallucinate, and imagine does not provide evidence in favor of the view that the brain contains pictures of the detailed environment.[15]

A corollary of this confusion about dreams and mental imagery is the idea, expressed by a number of authors (e.g., Farah 1989; Kosslyn 1994; Zeki 1993) that feedback from higher brain areas into the retinotopic cortical map of area V1 would be a good way of creating mental imagery. This argument is somewhat misleading. It could be taken to be based on the implicit assumption that mental imagery occurs because of activation in V1: the topographic, metric layout of V1 would make it a good candidate for the cortical areas that possess what Zeki (1993) has called an "experiential" quality – that is, the capacity to generate experience. But again, the metric quality of V1 cannot in any way be the cause for the metric quality of our experience. It is as though, in order to generate letters on one's screen, the computer had to have little letters floating around in its electronics somewhere.

There may also be a second confusion at work in the argument from dreaming that we are considering. We have already noted that it does not follow from the fact that dreams are pictorial that, when we dream, there are pictures in the head. But do we really have reason to believe that dreams are pictorial? People certainly do say that they are. But does this give us reason to believe it is so? Just as we have observed that the idea that seeing is pictorial reflects a kind of naïve phenomenology of vision, it may very well be that the claim that dreaming is pictorial is similarly ill-founded phenomenologically. Certainly it is not the case that when we dream, it is as if we were looking at pictures. A hallmark of dream-like experiences is the unstable and seemingly random character of dreamt detail. For example, the writing on the card is different every time you look at it in the dream.[16] This suggests that without the world to serve as its own external model, the visual system lacks the resources to hold an experienced world steady.

4.5. Seeing without eye movements

Under the theory presented here, seeing involves testing the changes that occur through eye, body, and attention movements. Seeing without such movements is, under the theory, a subspecies of seeing: an exception. This would appear to be a rather dissident claim, given that psychologists studying visual perception have devoted a significant part of their energy precisely to the use of tachistoscopic stimulus presentation techniques, where stimuli are displayed for times shorter than the saccadic latency period of about 150 msec required for an eye movement to occur. Indeed, the studies show that observers are perfectly able to see under these conditions. For example, Potter (1976), in now classic experiments, showed that observers could pick out a target picture in a series of pictures presented at rates as fast as one picture every 125 msec. Thorpe et al. (1996) refined Potter's technique and showed by using event-related EEG potentials, that 150 msec after a stimulus is presented, that is, without any eye movement occurring, there is already information available in the cortex allowing the presence of an animal in a picture to be ascertained.

But because highly familiar stimuli (like words or animals) are used in these experiments, observers may be making use of a few distinctive features available in the images in order to accomplish the task. As argued by Neisser (1976), it probably cannot be said that observers are "seeing" the pictures in the normal sense of the word. As an illustration, consider an experiment we performed in which observers were asked to learn to distinguish three previously unknown symbols resembling Chinese characters (Nazir & O'Regan 1990). These were presented under the control of a computer linked to an eye movement measuring device. In the experiment, conditions were arranged so that observers could contemplate each Chinese symbol with their eyes fixated at the middle of the symbol, but as soon as the eyes moved, the symbol would disappear. Observers found this procedure extremely disrupting and irritating, and, contrary to what happens when the eye is free to move, hundreds of trials were necessary before they were able to distinguish the symbols. Furthermore, once the task was learnt, observers often failed when asked to recognize the learnt patterns at a new retinal location, only as little as half a degree away from the learnt position. Schlingensiepen et al. (1986) also found that without eye movements, observers had difficulty distinguishing patterns composed of arrays of random black and white squares; and Atkinson et al. (1976) showed by using an after-image technique that it is impossible to count more than four dots that are fixed with respect to the retina: a rather surprising fact. In a task of counting assemblies of debris-like pixel clumps, Kowler and Steinman (1977) found that observers had difficulties when eye movements were not permitted.[17] Because the stimuli used in these experiments were well above the acuity limit, the results are not explicable by acuity drop-off in peripheral vision. Even though a portion of the results may be due to lateral interaction effects (e.g., Toet & Levi 1992), it seems clear that observers are not at ease when doing a recognition task where eye movements are prohibited. It is like tactually trying to recognize an object lain on your hand without manipulating it.

A further suggestion of the need for visual exploration concerns the phenomenon of fading that occurs when the retinal image is immobilized artificially by use of an optical stabilization device. Under these circumstances a variety of perceptual phenomena occur, ranging from loss of contrast, to fragmentation, to the visual field becoming gray or "blacker than black" (Ditchburn 1973; Gerrits 1967). A portion of these phenomena can undoubtedly be accounted for in terms of the temporal response of the first stages of the visual system. Kelly (1982), for example, has suggested that detectors sensitive to oriented lines such as those discovered by Hubel and Wiesel actually are silent unless the oriented line stimulation is temporally modulated. Laming (1986; 1988) has stressed that neural transmission of external stimulation is always differentially coupled, so that, for example, the response of the retina to static stimulation is weak, and temporal modulation is necessary for optimal response (see also Arend 1973; Gerrits 1978; Kelly 1981; Krauskopf 1963).

From the point of view of the present theory, these phenomena are compatible with the idea that sensing of the visual world is a dynamic probing process. It could be that even the presence of a static external stimulus is not registered by a static sensory input, but by the dynamic pattern of the inputs that would potentially be produced by changes in the sensor position.

4.6. Why we don't see behind ourselves, but we do see partially occluded objects

Consider objects behind you, or in a box on your desk. Though you *know* that turning around or opening the box will cause certain changes in your sensory stimulation, some of which are indeed visual in nature, you do not have the feeling of *seeing* things behind you or in the box. The reason is that while the objects are behind you or in the box, the knowledge you have does not include certain essential visual aspects, namely, the knowledge that, say, blinking or moving your eyes will modify the sensations in a way typical of things that you see.

On the other hand, closer to normal seeing, consider an object which is partially occluded by another object. As you move your head, previously occluded parts appear, and previously unoccluded parts may disappear behind the occluder. This ability to make parts of the occluded object appear and disappear is similar to the ability to make objects appear and disappear by blinking, or to make their retinal projections change by moving the eye towards and away from them. This kind of ability is typical of what it is to see, so, even though the object is partially occluded, you nevertheless have the impression of seeing it, or at least "almost" seeing it. Furthermore, if you suddenly close your eyes and ask yourself exactly how much of the object was actually visible just before you closed your eyes, you will not generally know, and indeed, as suggested by results of Intraub and Richardson (1989), you will generally think you saw more than you did (see Fig. 2). This demonstrates that seeing is not directly related to having a retinal image, but to being able to manipulate the retinal image.

5. Empirical data

5.1. Introduction

In this section we will lay out a number of empirical results which are related to the theory of visual experience we have sketched. Before beginning however, it should be stressed that the empirical data to be presented is not intended as a *test* of the theory in the everyday sense in which theories are tested in science. We are providing a general framework for the study of vision, and it is not possible to subject a general framework to direct verification. Our new framework provides scientists with new problems and it makes some old problems appear as non-problems (like the problem of visual stability despite eye movements, and the problem of filling in the blind spot – see below). The framework highlights links between previously unrelated research streams, and creates new lines of research (like the work on change blindness, which was initiated by the idea of "the world as

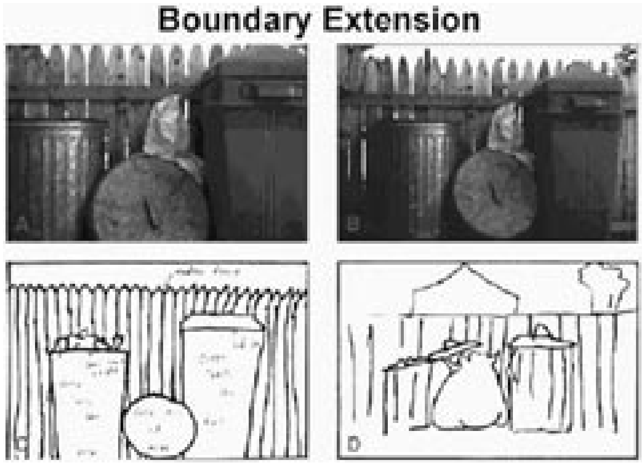

Figure 2. Subjects tend to remember having seen a greater expanse of a scene than was shown in a photograph. For example, when drawing the close-up view in Panel A from memory, one subject's drawing (Panel C) contained extended boundaries. Another subject, shown a more wide-angle view of the same scene (Panel B), also drew the scene with extended boundaries (Panel D). (Note: To evaluate the drawings in the figure, it is important to study the boundaries of each drawing and its associated stimulus.) (Figure and caption from Intraub, http://www.psych.udel.edu/~intraub)

an outside memory"). Of course, in each case, local, alternate, theories are possible within each of these domains, but the advantage of the present approach is that it brings together all the results so they can be seen from a single viewpoint.

In understanding the epistemological role of the present theory, an analogy can be made with the situation facing nineteenth-century physicists, who were trying to invent mechanisms by which gravitational or electrical forces could act instantaneously at a distance. To solve this problem, Faraday developed the idea of a *field of force* which was, according to Einstein, the single most important advance in physics since Newton (cf. Balibar 1992). But, in fact, the idea of a field of force is not a theory at all, it is just a new way of defining what is meant by force. It is a way of abandoning the problem being posed, rather than solving it. Einstein's abandoning the ether hypothesis is another example of how advances can be made by simply reformulating the questions one allows oneself to pose.

In the experiments to be described below, the first group relates to the notion that there is no picture-like internal representation of the outside world and that the world serves as an outside memory. These studies concern the problem of the apparent stability of the visual world despite eye movements, the filling-in of the blind spot and other (supposed) visual defects, and "change blindness": the fact that large changes in a visual scene sometimes go unnoticed. The second group of studies is more related to the idea that visual experience only occurs when there is the potential for action. These studies concern sensorimotor adaptation, sensory substitution, and synesthesia-related effects.

5.2. The extraretinal signal

At least since Helmholtz toward the end of the last century, a classic problem in vision has been to understand why the perturbations caused by eye movements (shift and smear on the retina) do not interfere with our perception of a stable visual world (cf. reviews of Bridgeman 1995; Grüsser 1986; MacKay 1973; Matin 1972; 1986; Shebilske 1977). A large portion of the experimental literature on the subject has assumed the existence of an internal representation, like a panoramic internal screen, into which successive snapshots of the visual world are inserted so as to create a fused global patchwork of the whole visual environment. The appropriate location to insert each successive snapshot is assumed to be determined by an "extraretinal signal," that is, a signal reflecting the direction the eyes are pointed at every moment. In total darkness some sort of extraretinal information is certainly available, as can easily be ascertained by noting that the after-image of a strong light source seems to move when the eyes move (Mack & Bachant 1969). Much debate has occurred concerning the question of whether the extraretinal signal is of efferent or afferent origin, and a convincing estimation of the role of the two components has been made by Bridgeman and Stark (1991). Irrespective of its origin however, the data concur to show that if the extraretinal signal exists, it is very inaccurate. Measurements from different sources (cf., e.g., compilations in Matin 1972; 1986) show that the signal must incorrectly be signaling that the eye starts to move as much as 200 msec before it actually does. The signal also incorrectly estimates the time and position where the eye lands, becoming accurate only about 1 second after the eye has reached its final position.[18] In any case, as admitted by Matin (1986), it is clear that the extraretinal information is too inaccurate, and also too sluggish, given the frequency of eye movements, to be used under normal viewing conditions to accurately place successive snapshots into a global fused internal image.

These results are not surprising when considered from the point of view of the theory of vision presented here. From this viewpoint, there is no need to postulate a mechanism that re-positions the retinal image after eye saccades so that the world appears stationary, because what is meant by "stationary," is precisely one particular kind of sensory change that occurs when the eye moves across an object. Having the feeling of seeing a stationary object consists in the knowledge that if you were to move your eye slightly leftwards, the object would shift one way on your retina, but if you were to move your eye rightwards, the object would shift the other way. The knowledge of all such potential movements and their results *constitute* the perception of stationarity. If on actually moving the eyes there were no corresponding retinal motion, the percept would not be of stationarity. From this point of view, there is no need to construct a stationary internal "image" of an object in order to see it as stationary. If there is such a thing as an internal signal in the brain that signals the eye's instantaneous position, then its purpose could not be to construct such an internal image (for there would be no one to look at it).

The question nevertheless arises of how the brain is able to accurately judge whether an object is stationary, or to control visuomanual coordination. If there is no way for retinal and extraretinal information to be combined to yield the true spatial coordinates of an object, how can the motion of an object ever be accurately ascertained, or how can an object be located with respect to the body and grasped? A possible answer may be that, whereas there is no extraretinal *signal,* there is nevertheless extraretinal *information* about the eye's location or velocity in the orbit. This information could be present in distributed form, and confounded with information about retinal stimulation. Such a distributed representation that mixes sensory and motor information (both of a static kind – position – and of a dynamic kind – velocity, acceleration) could provide the knowledge about sensorimotor contingencies required in the present theory. It could be used to perform accurate localization, but would not require the existence of a metric-preserving representation of the eye's position, or a picture-like internal image of objects on the retina or in space. Perhaps the multisensory neurons observed in parietal cortex, whose responses may be modulated by imminent eye movements, are compatible with this idea (Colby et al. 1996; Duhamel 1992; see also Zipser & Anderson 1988). Also of interest with respect to these ideas is a model of visual localization despite eye movements that has been constructed by Pouget and Sejnowski (1997). The model uses basis functions to code nonlinear mixtures of retinal and eye position. Linear combinations of these basis functions can provide pure retinal position, pure eye position, or head-centered coordinates of a target, despite the fact that no coherent internal map of the visual field has been constructed.

5.3. Trans-saccadic fusion

Over recent decades a new research topic has arisen with regard to the question of visual stability, in which researchers, instead of measuring the extraretinal signal itself, are questioning the notion that underlies it, namely, the notion of an internal screen in which successive snapshots are accumulated. The experimental methodology of this work consists in displaying stimuli which temporally straddle the eye saccade, and attempting to see if observers see a fused image – this would be predicted if an internal screen exists. Excellent reviews of this work (Irwin 1991; 1992) conclude that trans-saccadic fusion of this kind does not exist, or at least is restricted to a very small zone, namely, the zone corresponding to the target which the saccade is aiming for. Another kind of experiment consists in making large changes in high quality, full color pictures of natural scenes in such a way that the changes occur during an eye saccade (McConkie & Currie 1996). Even though the changes can occupy a considerable fraction of the field of view (e.g., cars appear or disappear in street scenes, swimming suits worn by foreground bathers change color, etc.), they are often not noticed – also contradicting the idea of a pictorial-type internal representation of the visual world. Again the conclusion appears to be that if there is an internal screen, it is not this internal screen which is providing us with the sensation of a stable, panoramic, visual world (Irwin & Andrews 1996; Irwin & Gordon 1998).

This conclusion is consistent with the theory presented here, where the problem of visual stability is a non-problem. Seeing does not require compensating for the effects produced by eye shifts in order to ensure accurate accumulation of partial views into a composite patchwork projected on some internal screen. There is no need to recreate another world inside the head in order for it to be seen. Instead, as suggested in section 4, the outside world acts as an "external memory" store, where information is available for probing by means of eye movements and shifts of attention O'Regan (1992).[19]

5.4. Saccadic suppression

Another issue which has preoccupied scientists concerns the question of why we are not aware of the smear caused by saccades. An enormous literature on the topic has been reviewed by Matin (1974; cf. also Li & Matin 1997): it appears that both at that time and still today (e.g., Burr et al. 1994; Li & Matin 1990; Ridder & Tomlinson 1997; Uchikawa & Sato 1995) many researchers believe that it is necessary to postulate some kind of suppression mechanism that inhibits transmission of sensory information to awareness during saccades, so that the rather drastic saccadic smear is not seen.

The empirical evidence showing diminished sensitivity to flashes during saccades cannot be denied, and the origin of this effect has been estimated by Li and Matin (1997) to be 20% due to the retinal smearing and masking caused by the image displacement (there may also be mechanical effects, as suggested by Richards 1969), and 80% due to central inhibitory mechanisms (some portion of this may be due to spatial uncertainty caused by the new eye position, cf. Greenhouse & Cohn 1991).

The important point, however, is that whatever inhibitory effects are occurring during saccades, these certainly do not constitute a suppression mechanism designed to prevent perception of the saccadic smear. If they did, then why would we not perceive a dimming of the world during saccades? Would we have to postulate a further un-dimming mechanism to compensate for the dimming? The notion of saccadic suppression probably constitutes another instance of the homunculus error, and is no less naive than postulating the need for a mechanism to right the upside-down retinal image so that the world appears right-side up. As explained in the theory presented above, there is no need to postulate mechanisms that compensate for the smear that is created by eye saccades, because this smear is part of what it is to see. If the retinal receptors did not signal a global smear during saccades, then the brain would have to assume that the observer was not seeing, and that he or she was perhaps hallucinating or dreaming.

5.5. Filling in the blind spot and perceptual completion

Another classic problem in vision which has recently been revived and generated heated debate (e.g., Ramachandran 1992; Ramachandran & Gregory 1991; Ramachandran 1995 vs. Durgin et al. 1995) is the problem of why we do not generally notice the 5–7 degree blind spot centered at about 17 degrees eccentricity in the temporal visual field of each eye, corresponding to the blind location on the retina where the optic nerve pierces through the eyeball.

Related problems involve understanding the apparent filling in of brightness or color that occurs in phenomena such as the Craik-O'Brian-Cornsweet effect and neon color spreading; the apparent generation of illusory contours as in the Kanisza triangle; and other phenomena of modal or amodal completion (cf. reviews of Kingdom & Moulden 1992; Pessoa et al. 1998).

Taking the case of the blind spot, from the point of view of the present theory, and in agreement with analyses of a number of theoreticians (Kingdom & Moulden 1992; Pessoa et al. 1998; Todorovič 1987), there is no need for there to be any filling in mechanism (O'Regan 1992). On the contrary, the blind spot can be *used* in order to see: if retinal sensation were not to change dramatically when an object falls into the blind spot, then the brain would have to conclude that the object was not being seen, but was being hallucinated. Suppose you explore your face with your hand: you can put your hand in such a way that your nose falls between two fingers. This does not give you the haptic impression of having no more nose. On the contrary, being able to put the nose between two fingers gives information about the size and nature of a nose. It is part of haptically perceiving the nose.

Monitoring the way the sensory stimulation from the retina changes when the eye moves to displace an object in the vicinity of the blind spot, is, for the brain, another way of gaining information about the object.

One can argue, however, that even though there may be no *need* for filling in processes, such filling in processes may nevertheless actually exist. In support of this, Pessoa et al. (1998), though critical of some neurophysiological and behavioral studies purporting to be evidence for filling in, concluded that several studies do point to the existence of precisely the kind of mechanisms which would be required for a filling in process. For example, Paradiso and Nakayama (1991), by using a masking paradigm, were able to measure the temporal dynamics of the phenomenal filling in of the inside of a bright disk. De Weerd et al. (1995) found cells in extrastriate cortex whose responses correlate well with the time it takes for the holes in textures presented in peripheral vision to perceptually fill in.

Just as was the case for the problem of the extraretinal signal or of saccadic suppression, the theory being advocated here does not deny the existence of neural mechanisms that underlie the perceptual phenomena that each of us observe. There can be no doubt that something is going on in the brain which is in relation to the fact that observers have no experience of a blind spot, and which makes Kanisza triangles have illusory contours. The question is: Is whatever is going on, actually serving to create an internal copy of the outside world, which has the metric properties of a picture, and which has to be completed in order for observers to have the phenomenology of a perfect scene? In the example of Paradiso and Nakayama's data, for example, there can be no denying that there must be retinal or cortical processes that involve some kind of dynamic spreading activation and inhibition, and that these processes underlie the percept that observers have in their paradigm – and possibly also when a disk is presented under normal conditions. But even though these processes *act like* filling in processes, this does not mean that they *are actually used by the brain* to fill in an internal metric picture of the world. They may just be providing information to the brain about the nature of the stimulation, but without this information being used to create a picture-like representation of the world.

In other words, our objection is not to the mechanisms themselves, whose existence we would not deny, but to the characterization of these mechanisms as involving "filling in." Consider this caricature: Spatio-temporal integration in the low-level visual system is a mechanism which explains much phenomenology (e.g., why fast flickering lights appear continuous, and very closely spaced dots look like lines). But surely no one would want to claim that the purpose of spatiotemporal integration is to "fill in" the temporal gaps in what would otherwise look like a stroboscopic world, or to make dotted lines look continuous. Spatiotemporal integration is a mechanism used in our visual systems to sample the environment, but its purpose is not to compensate for gaps in what would otherwise be a granular, pixel-like internal picture.

5.6. Other retinal non-homogeneities and the perception of color

A striking characteristic of the human visual system is its non-homogeneity. Spatial resolution is not constant across the retina, but falls off steadily: even the central foveal area is not a region of constant acuity, since at its edge (i.e., at an eccentricity of about 1 degree), position acuity has already dropped to half its value at the fovea's center (Levi et al. 1985; Yap et al. 1989). This drastic fall-off continues out into peripheral vision, only slowing down at around 15 degrees of eccentricity.

In addition to this non-homogeneity in spatial sampling, the retina also suffers from a non-homogeneity in the way it processes color: whereas in the macular region, the presence of three photoreceptor cone classes permits color discrimination, in the peripheral retina the cones become very sparse (Anderson et al. 1991; Coletta & Williams 1987; Marcos et al. 1996). The lack of the ability to accurately locate colors can easily be demonstrated by attempting to report the order of the colors of four or five previously unseen colored pencils when these are brought in from peripheral vision to a position just a few degrees to the side of one's fixation point.

A further, surprising non-homogeneity derives from the macular pigment, a yellowish jelly covering the macula, that absorbs up to 50% of the light in the short wavelength range (Bone et al. 1992), thereby profoundly altering color sensitivity in central vision.

Despite these non-homogeneities, the perception of spatial detail and color does not subjectively appear non-uniform to us: most people are completely unaware of how poor their acuity and their color perception are in peripheral vision. Analogously to the filling-in mechanism that is sometimes assumed to fill in the blind spot, one might be tempted to postulate some kind of compensation mechanism that would account for the perceived uniformity of the visual field. However, from the point of view of the present theory of visual experience, such compensation is unnecessary. This will be illustrated in relation to color perception below.

5.7. "Red" is knowing the structure of the changes that "red" causes

Under the present view of what seeing is, the visual experience of a red color patch depends on the *structure of the changes* in sensory input that occur when you move your eyes around relative to the patch, or when you move the patch around relative to yourself. For example, suppose you are looking directly at the red patch. Because of absorption by the macular pigment, the stimulation received by the color-sensitive retinal cones will have less energy in the short wavelengths when you look directly at the red patch, and more when you look away from the patch. Furthermore, since there is a difference in the distribution and the density of the different color-sensitive cones in central versus peripheral vision, with cone density dropping off considerably in the periphery, there will be a characteristic change in the relative stimulation coming from rods and cones that arises when your eyes move off the red patch. What determines the perceived color of the patch is the *set of such changes* that occur as you move your eyes over it.[20]

A relevant example arises from the perception of color in dichromats. When carefully tested in controlled conditions of illumination, dichromats exhibit deficiencies in their ability to distinguish colors, generally along the red-green dimension, which can be accounted for by assuming that they lack a particular type of cone, generally either the long or medium wavelength type. Curiously however, in real-life situations, dichromats are often quite good at making red-green distinctions. As suggested by Jameson and Hurvich (1978; cf. also Lillo et al. 1998) this is undoubtedly because they can make use of additional cues deriving from what they know about objects and what they can sense concerning ambient lighting. Thus, for example, when a surface is moved so that it reflects more yellowish sunlight and less bluish light from the sky, the particular way the spectrum of the reflected light changes, disambiguates the surface's color, and allows that color to be ascertained correctly even when the observer is a dichromat.

Though it is not surprising to find observers using all sorts of available cues to help them in their color discriminations, this kind of finding can be taken to support a much more far-reaching, fundamental hypothesis, put forward by Broackes (1992). This is that the color of a surface is not so much related to the spectrum of the reflected light, but rather, to the way the surface potentially *changes* the light *when the surface is moved with respect to the observer or the light sources.*

It must be stressed that more is being said here than was said by Jameson and Hurvich (1978), who merely noted that information is *available* that allows dichromats to make judgments similar to trichromats. Broackes' idea is that the colors of surfaces *are exactly* the laws governing the way the surface changes the reflected light.[21] At least as far as reflectivity of surfaces are concerned, the *same* laws apply to dichromats and trichromats, so that to a certain extent they have the *same* kinds of color perception: the difference is that dichromats have fewer clues to go by in many situations. Thus Broackes, who has color vision deficiencies[22] himself, claims that he has different experiences for red and green as do normals. His only problem is that sometimes, when lighting conditions are special, he can see certain dark red things as dark green, just as sometimes, in shadow, people with normal vision are convinced a garment is dark blue when in fact it is black, or vice versa. Of course, there will be a component of the sensorimotor contingencies, namely, those determined by the observer's own visual apparatus, which, to the extent that dichromats lack one of the three color channels, are different in the case of dichromats as compared to trichromats, so colors cannot be completely identical for them.

Broackes' theory of color is strongly related to the theory of visual perception that we have presented here. The difference between Broackes' views and ours is that Broackes is attempting to characterize the nature of *color* in terms of laws of sensorimotor contingency, whereas we have taken the bolder step of actually identifying color *experience* with the exercise of these laws, or, more precisely, with activity carried out in accord with the laws and based on knowledge of the laws.

5.8. Eye-position contingent perception

A surprising prediction from this idea, that the sensation of red comes from the *structure of changes* that is caused by red, is the following armchair experiment. Using a device to measure eye movements connected to a computer, it should be possible to arrange stimulation on a display screen so that whenever an observer looks *directly* at a patch of color it appears red, but whenever the observer's eye looks *away from* the patch, its color changes to green. The rather counterintuitive prediction from this is that after training in this situation, the observer should come to have the impression that green patches in peripheral vision and red patches in central vision are the same color.

Whereas exactly this kind of experiment has not yet been done, a variety of related manipulations were performed by McCollough (1965b) and by Kohler (1951).[23] For example, Kohler had observers wear spectacles in which one half of the visual field was tinted with blue, and the other half tinted with yellow. This is similar to the proposed armchair experiment in the sense that perceived color will be different depending on which way the observer moves the eyes. Results of the experiment seem to show that after adaptation, observers apparently came to see colors "normally." Similar phenomena were observed with half-prisms, in which the top and bottom portion of the visual field were shifted by several degrees with respect to each other. Observers ultimately adapted, so that manual localization of objects in the upper and lower visual fields was accurate.

Of particular interest in these studies would have been to know whether observers perceived the world as continuous despite the discontinuity imposed by the colored glasses or prisms. However, it is difficult to rigorously evaluate the reports, as they were only described informally by Kohler. Since then, though a large literature has developed over the last decades concerning many forms of perceptual adaptation, not very much work seems to have been done to investigate the effects of modifications like those imposed by the two-color glasses or the half-prisms, which produce strong discontinuities in the visual field.

Nevertheless, partial insight into such situations may be obtained by considering people who wear spectacles with bifocal lenses[24]: here a discontinuity exists in the visual field between the upper and lower part of the glasses. Depending on where an observer directs the eyes, the size and focus of objects will be different, because of the different power of the two parts of the lens. The question then is, does the world appear discontinuous to viewers of bifocals? The answer is that the *world* does not appear discontinuous, any more than the world appears "dirty" to someone who has not wiped his spectacle lenses clean. This is not to say that the observer cannot become aware of the discontinuity or the dirt on the lenses by attending to the appropriate aspect of the stimulation, just as it is possible to become aware of the blind spot in each eye by positioning a stimulus appropriately. But under normal circumstances the wearer of bifocals takes no notice of the discontinuity. Furthermore, even though image magnification as seen through the different parts of the lens are different, thereby modifying perception of distance, manual reaching for objects seen through the different parts of the lenses adapts and becomes accurate, as does the vestibulo-ocular reflex. Gauthier and Robinson (1975) and Gauthier (1976) have, for example, shown that wearers of normal spectacles with strong corrections, as well as scuba divers, come to possess a bistable state of adaptation, whereby their distance perception and reaching can instantaneously switch from one to the other state, as they take their spectacles on and off, or look through their underwater goggles (see also Welch et al. 1993 for a similar effect with prisms). In fact, an observer can be tricked into inappropriately switching adaptation state by surreptitiously removing the lenses from his or her eyeglasses, so that he or she incorrectly expects magnification to change when the eyeglasses are put on (Gauthier, personal communication).

5.9. Inversion of the visual world

Relevant to the theory of visual experience being proposed here, are the classic experiments performed by Stratton (1897), Kohler (1951), and some less often cited replications by Taylor (1962), Dolezal (1982), and Kottenhoff (1961), in which an observer wears an optical apparatus which inverts the retinal image so that the world appears upside-down and/or left-right inverted (cf. reviews by e.g., Harris 1965; 1980). Although at first totally incapacitated, observers adapt after a few days and are able to move around. Ultimately (after about two weeks of wearing the apparatus) they come to feel that their new visual world is "normal" again.[25]

What is interesting about these experiments is that during the course of adaptation, perception of the world is subject to a sort of fragmentation, and to a dependence on context and task. For example, Kohler (1951) reports that visual context allows something that is seen upside-down to be righted (e.g., a candle flips when it is lit because flames must go up, a cup flips when coffee is poured into it, because coffee must pour downwards). Ambiguities and inconsistencies abound: Dolezal reports sometimes being unable to prevent both his hands from moving when he tries to move only one. Kohler reports cases where two adjacent heads, one upright, the other inverted, were *both* perceived as upright. Kohler's observer Grill, after 18 days of wearing reversing spectacles, stands on the sidewalk and correctly sees vehicles driving on the "right," and hears the noise of the car motor coming from the correct direction. On the other hand, Grill nevertheless reports that the license plate numbers appear to be in mirror writing. Other observations are that a "3" is seen as in mirror writing, even though its open and closed sides are correctly localized as being on the left and right, respectively. The bicycle bell seems on the unusual side, even though the observer can turn the handle bars in the correct direction. Taylor (1962) has performed a study similar to Kohler's, except that instead of wearing the inverting spectacles continuously, his subject wore them only for a limited period each day. Under these conditions the subject rapidly obtains a bistable form of adaptation, adapted to both wearing and not wearing the spectacles. A point stressed by Taylor, in support of his behaviorist theory,[26] is that adaptation is specific to the particular body parts (arms, legs, torso) or activities (standing on both feet, on one foot, on the toes, riding a bicycle) that the subject has had training with, and that there is little "interpenetration" from one such sensorimotor system to another.

A theory of vision in which there is a picture-like internal representation of the outside world would not easily account for the fragmentation of visual perception described in these experiments: for example, it would be hard to explain the case of the license plate, where one aspect of a scene appears oriented accurately, and yet another aspect, *sharing the same retinal location,* appears inverted. On the other hand, the present theory, in which vision is knowledge of sensorimotor transformations, and the ability to act, readily provides an explanation: reading alphabetic characters involves a subspecies of behavior connected with reading, judging laterality involves another, independent, subspecies of behavior, namely, reaching. An observer adapting to an inverted world will in the course of adaptation only be able to progressively probe subsets of the sensorimotor contingencies that characterize his or her new visual world; and so inconsistencies and contradictions may easily arise between "islands" of visuo-motor behavior.[27]

Particularly interesting are cases of double vision when only one eye is open, that is, not explicable by diplopia. For example, Kohler's observer Grill saw two points of light when only one was presented slightly to the right of the median line (the second point was seen weaker, on the left, symmetrical to the original point). Similar observations of symmetrical "phantoms" were noticed by Stratton (1897), and can be compared to cases of monocular diplopia reported in strabismus (Ramachandran et al. 1994a; 1994b; Rozenblom & Kornyushina 1991). Taylor (1962) says of his subject wearing left-right inverting spectacles:

> Another of the training procedures he adopted was to walk round and round a chair or table, constantly touching it with his body, and frequently changing direction so as to bring both sides into action. It was during an exercise of this kind, on the eighth day of the experiment, that he had his first experience of perceiving an object in its true position. But it was a very strange experience, in that he perceived the chair as being both on the side where it was in contact with his body and on the opposite side. And by this he meant not just that he *knew* that the chair he saw on his left was actually on his right. He had that knowledge from the beginning of the experiment. The experience was more like the simultaneous perception of an object and its mirror image, although in this case the chair on the right was rather ghost-like. (pp. 201–202)

Presumably what happens in these experiments is that, because the spatial location or orientation of an object with respect to the body can be attributed either with respect to the pre- or the post-adapted frame of reference, during the course of adaptation it can sometimes be seen as being in both. Furthermore, orientation and localization of objects in the field of view can be defined with respect to multiple referents, and within different tasks, and each task may have adapted independently, thereby giving rise to incoherent visual impressions.

The impression we have of seeing a coherent world thus arises through the knitting together of a number of separate sensory and sensory-motor components, making use of visual, vestibular, tactile, and proprioceptive information; and in which different behaviors (e.g., reading, grasping, bicycle riding) constitute components that adapt independently, but each contribute to the experience of seeing. Conclusions of this kind have also been reached in a wealth of research on sensorimotor control, where it is shown that a gesture such as reaching for an object is composed of a number of sub-components (e.g., ballistic extension of the arm, fine control of the final approach and finger grasping, etc.), each of which may obey independent spatial and temporal constraints, and each of which may be controlled by different cerebral subsystems, which adapt separately to perturbations like changes in muscle proprioception, or in vestibular and visual information (for reviews of these results, see Jeannerod 1997; Rossetti et al. 1993).[28]

5.10. Change blindness experiments

The idea that the world constitutes an outside memory, and that we only see what we are currently attending to, was the impetus for a number of surprising experiments performed recently on "change blindness"[29] (O'Regan et al. 1999; 2000; Rensink et al. 1997; 2000). In these experiments, observers are shown displays of natural scenes, and asked to detect cyclically repeated changes, such as a large object shifting, changing color, or appearing and disappearing. Under normal circumstances a change of this type would create a transient signal in the visual system that would be detected by low-level visual mechanisms. This transient would exogenously attract attention to the location of the change, and the change would therefore be immediately seen.

However, in the change blindness experiments, conditions were arranged such that the transient that would normally occur was prevented from playing its attention-grabbing role. This could be done in several ways. One method consisted in superimposing a very brief global flicker over the whole visual field at the moment of the change. This global flicker served to swamp the local transient caused by the change, preventing attention from being attracted to it. A similar purpose could be achieved by making the change coincide with an eye saccade, an eye blink, or a film cut in a film sequence (for reviews, see Simons & Levin 1997).[30] In all these cases a brief global disturbance swamped the local transient and prevented it attracting attention to the location of the change. Another method used to prevent the local transient from operating in the normal fashion was to create a small number of additional, extraneous transients distributed over the picture, somewhat like mudsplashes on a car windscreen (cf. O'Regan et al. 1999). These local transients acted as decoys and made it likely that attention would be attracted to an incorrect location instead of going to the true change location.

The results of the experiments showed that in many cases observers have great difficulty seeing changes, even though the changes are very large, and occur in full view – they are perfectly visible to someone who knows what they are. Such results are surprising if one espouses the view that we should "see" everything that we are looking at: It is very troubling to be shown a picture where a change is occurring repetitively and in full view, without being able to see the change. The experience is quite contradictory with one's subjective impression of richness, of "seeing everything" in the visual field. However, the results are completely coherent with the view of seeing which is being defended here.

Another aspect of these experiments which relates to the present theory is a result observed in an experiment in which observers' eye movements were measured as they performed the task (O'Regan et al. 2000). It was found that in many cases, observers could be looking directly at the change at the moment the change occurred, and still not see it. Again, under the usual view that one should see what one is looking at, this is surprising. But under the view that what one sees is an aspect of the scene one is currently "visually manipulating," it is quite reasonable to observe that only a subset of scene elements that share a particular scene location should at a given moment be perceived.

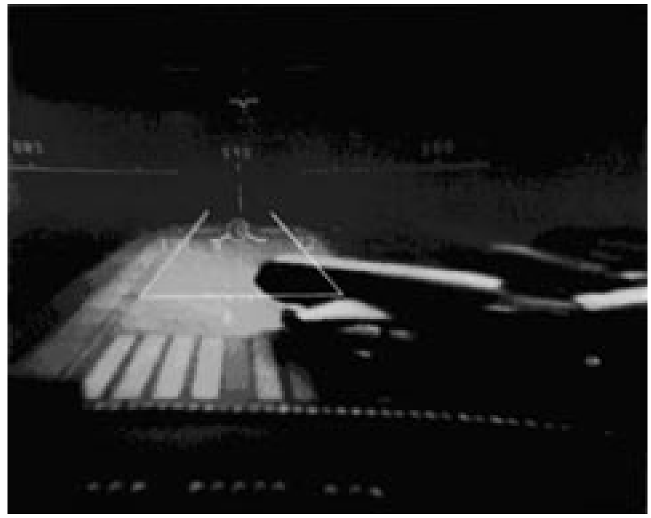

Figure 3. Simulator pilot's forward visual scene at an altitude of 72 feet and 131 knots with runway obstruction clearly visible. From Haines (1991). (Photo courtesy of NASA.)

A striking result of a similar nature had been observed by Haines (1991) and Fisher et al. (1980), who had professional pilots land an aircraft in a flight simulator under conditions of poor visibility, and using a head-up display (or "HUD") – that is, a display which superimposed flight guidance and control information on the windshield. On various occasions during the pilot's landing approach, they were presented with unexpected "critical" information in the form of a large jet airplane located directly ahead of them on the runway. Although the jet airplane was perfectly visible despite the head-up display (see Fig. 3), presumably because of the extreme improbability of such an occurrence, and because the pilots were concentrating on the head-up display or the landing maneuver, two of the eight experienced commercial pilots simply did not see the obstacle on the two occasions they were confronted with it, and simply landed their own aircraft through the obstacle. On later being confronted with a video of what had happened, they were incredulous.[31]

Other results showing that people can be looking directly at something without seeing it, had previously been obtained by Neisser and Becklen (1975), who used a situation which was a visual analogue of the "cocktail party" situation, where party-goers are able to attend to one of many superimposed voices. In their visual analogue, Neisser and Becklen visually superimposed two independent film sequences, and demonstrated that observers were able to single out and follow one of the sequences, while being oblivious of the other. Simons and Chabris (1999) have recently replicated and extended these effects.

Finally, Mack and Rock (1998) and Mack et al. (1992) have done a number of experiments using their paradigm of "inattentional blindness." In this, subjects will be engaged in an attention-intensive task such as determining which arm of a cross is longer. After a number of trials, an unexpected, perfectly visible, additional stimulus will appear near the cross. The authors observe that on many occasions this extraneous stimulus is simply not noticed.[32]

5.11. Inattentional amnesia

Related to the idea that the world serves as an outside memory, are the intriguing experiments of Wolfe (1997; 1999), and Wolfe et al. (1999) which they interpret in terms of what they call "inattentional amnesia."

Wolfe et al. (1999) use a standard visual search paradigm in which a subject must search for a target symbol among a number of distractor symbols. The authors estimate the efficiency of the search in milliseconds per item searched. However, instead of using a new display of distractors on each trial as is usually done, the authors use *exactly the same visual display* over a number of repetitions, but each time change the target that the subject is looking for. Since subjects are looking at the same display, which *remains continuously visible* on the screen for anything from 5 to 350 repetitions, depending on the experiment, one might have expected that an internal representation of the display would have time to build up, allowing search rate to improve over repetitions. However, this is not what is found: Over a number of experiments using different kinds of stimuli, Wolfe et al. (1999) find no evidence of improvement in search rate. It seems that no internal representation of the display is being built up over repetitions. In fact, search rate is as bad after many repeated searches as in the normal visual search conditions when the display changes at every trial: in other words, it is as though the subjects think they are searching through a brand new display at each trial, even though it is exactly the same display as before. Furthermore, an experiment done where the display is memorized and not visually presented at all, actually shows *faster* search speeds than when the display is present.

The results of these experiments are surprising under the view that what we see consists of an internal, more or less picture-like, representation of the visual world. However, they are exactly what would be expected under the present view, according to which "seeing" consists, not of having a "picture" in the mind, but of having seeking-out-routines that allow information to be obtained from the environment. Thus, observers generally do not bother to recreate within their minds a "re"-presentation of the outside world, because the outside world itself can serve as a memory for immediate probing. Indeed, the last result showing faster performance in the pure memory search shows that the very presence of a visual stimulus may actually obligatorily cause observers to make use of the world in the "outside memory" mode, even though it is less efficient than using "normal" memory.

This way of interpreting the results is also in broad agreement with Wolfe's point of view (Wolfe 1997; 1999) – Wolfe also refers to the notion of "outside memory." However, Wolfe lays additional emphasis on the role of attention in his experiments: Following the approach of Kahneman et al. (1992) adopted by many researchers in the attention literature, Wolfe believes that before attention is brought to bear on a particular region of the visual field, the elementary features (such as line segments, color patches, texture elements) analyzed automatically by low-level modules in the visual system constitute a sort of "primeval soup" or undifferentiated visual "stuff." Only once attention is applied to a particular spatial location, can the features be bound together so that an object (or recognizable visual entity) is perceived at that location. Wolfe's interesting proposition is that now, when visual attention subsequently moves on to another location, the previously bound-together visual entities disaggregate again and fall back into the "primeval soup": the previously perceived entity is no longer seen. This idea prompts Wolfe to use the term "inattentional amnesia," to emphasize the fact that after attention has moved on, nothing is left to see.

The status of the notion of attention in this explanation, and its relation to the theory presented here, is not entirely clear. One possibility would be to assume that what Wolfe means by "attention" is nothing other than visual awareness. In that case, the result of the experiment could be summarized by saying "once your awareness has moved off a part of the scene, you are no longer aware of it," which is tautological. Presumably, therefore, what Wolfe means by attention is something independent of awareness: there would be forms of attention without awareness and forms of awareness without attention. It is clear that further thought is needed to clarify these questions.

Independently of the framework within which one places oneself, it remains an interesting question to ask: What does the primeval soup "look like"? In other words, what does the visual field look like when the observer is not attending to anything in particular in it? Our preference would be to take the strict sense of attention in which attention = awareness, and to say that without attending to something (i.e., without being aware of anything), by *definition* the visual field cannot look like anything at all. Only when the observer attends to something will he or she be aware of seeing it. Note that what the observer attends to can be something as basic as overall brightness or color, or something like the variability in these ("colorfulness"?, "texturedness"?), or some attribute like "verticality" or "blobiness." If such features constitute the "primeval soup," then, like normal targets in the search task, the primeval soup would also only be "seen" if it was being attended to.

5.12. Informal examples

While the examples given in the preceding sections are striking experimental demonstrations of the fact that you do not always see where you look, several more informal demonstrations also speak to the issue.

Proofreading is notoriously difficult: when you look at words, you are processing words, not the letters that compose them. If there is an extra, incorrect letter in a word, it will have been processed by your low-level vision modules, but it will not have been "seen." Thus, for example, you will probably not have noticed that the "a"s in the last sentences were of a different shape than elsewhere.[33] Nonetheless on several occasions you were undoubtedly looking directly at them. It may take you a while to realize that the sign below (Fig. 4) does not say: The illusion of

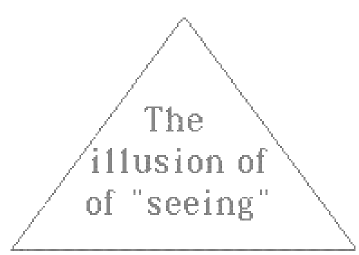

Figure 4. Ceci n'est pas: The illusion of "seeing."

Figure 5. Figure-ground competition.

"seeing."[34] You may be furious to find confirmation of years of the scientific study of reading showing that in this sentence there are in fact more "f"s than you think (count them!).[35]

The phenomena of figure-ground competition (see Fig. 5) and of ambiguous figures are also striking examples of how you do not see everything that you could see: when looking at such stimuli, you only see one of the possible configurations, even though more than one may be simultaneously available at the same location in your visual field.

It sometimes occurs that as you walk in the street you look directly at someone without seeing them. Only when the person gesticulates or manifests their irritation at not being recognized, do you become aware of who they are. While driving; it sometimes happens that you realize that you have been looking for a while at the brake lights of the car ahead of you without pressing on the brake.

5.13. Remote tactile sensing

An immediate consequence of the notion that experience derives not from sensation itself, but from the rules that govern action-related changes in sensory input, is the idea that visual experience should be obtainable via channels other than vision, provided that the brain extracts the same invariants from the structure of the sensori-motor contingencies.

A number of devices have been devised to allow people with deficits in one sensory modality to use another modality to gain information. In the domain of vision, two main classes of such sensory substitution devices have been constructed: echolocation devices and tactile visual substitution devices.

Echolocation devices provide auditory signals which depend on the direction, distance, size, and surface texture of nearby objects, but they provide no detailed shape information. Nevertheless, such devices have been extensively studied as prostheses for the blind, both in neonates (Bower 1977; Sampaio 1989; Sampaio & Dufier 1988) and in adults (Ifukube et al. 1991). It is clear that while such devices obviously cannot provide visual experience, they nevertheless provide users with the clear impression of things being "out in front of them."

Particularly interesting is the work being done by Lenay (1997), using an extreme simplification of the echolocation device, in which a blind or blindfolded person has a single photoelectric sensor attached to his or her forefinger, and can scan a simple environment (e.g., consisting of several isolated light sources) by pointing. Every time the photosensor points directly at a light source, the subject hears a beep or feels a vibration. Depending on whether the finger is moved laterally, or in an arc, the subject establishes different types of sensorimotor contingencies: lateral movement allows information about direction to be obtained, movement in an arc centered on the object gives information about depth. Note several interesting facts. First, users of such a device rapidly say that they do not notice vibrations on their skin or hear sounds, rather they "sense" the presence of objects outside of them. Note also that at a given moment during exploration of the environment, subjects may be receiving no beep or vibration whatsoever, and yet "feel" the presence of an object before them. In other words, the experience of perception derives from the *potential* to obtain changes in sensation, not from the sensations themselves. Note also that the exact nature or body location of the stimulation (beep or vibration) has no bearing on perception of the stimulus – the vibration can be applied on the finger or anywhere else on the body. This again shows that what is important is the sensorimotor invariance structure of the changes in sensation, not the sensation itself.

Lenay's very simple setup provides a concrete example of what is meant by the laws of sensorimotor contingency. Suppose that the photosensor were mounted on the forearm of an articulated arm, with the arm making an angle α with the torso, and the forearm making an angle β with the arm, as shown in the Figure 6. Then we can define the sensorimotor manifold as the two-dimensional space α: $[0, \pi/2]$ and β: $]3\pi/2\text{-a}, 2\pi[$. Consider the situation where we are obtaining information about depth by making movement in an arc. If a luminous source at distance L is being "fixated," the angles α and β will lie on orbits in the sensorimotor sensorimotor manifold defined by the relation shown in the lower part of the figure. In reality of course the angles α and β will be nonlinear functions of high-dimensional neural population vectors corresponding to arm and forearm muscle parameters. But the laws of contingency will be the same.

On further reflection it is apparent that the simple device studied by Lenay is an electronic variant of the blind person's cane. Blind persons using a cane do not sense the cane, but the outside environment that they are exploring by means of the cane. It has been said that the tactile sensations provided by the cane are somehow "relocated" or "projected" onto the environment. The cane itself is forgotten or ignored. But this way of describing experience with the cane, though in a way correct, is misleading, as it suggests that sensations themselves originally possessed a location which had to be relocated. The present theory shows that in themselves, sensations are situated nowhere. The location of a sensation (and, for that matter, any perceived aspect including its moment of occurrence) is an abstraction constructed in order to account for the invariance structure of the available sensorimotor contingencies.

Note that similar experiences to those of the blind person with the cane are experienced every day even by sighted persons: Car drivers "feel" the wheels on the road, and extend the sense of their bodies to include the whole car, allowing them to negotiate into parking spaces with only centimeters to spare. A particularly poignant example of having one's perceived body extend outside of the boundary formed by the skin was given to the first author by a friend who is a talented viola player. Spending most of the

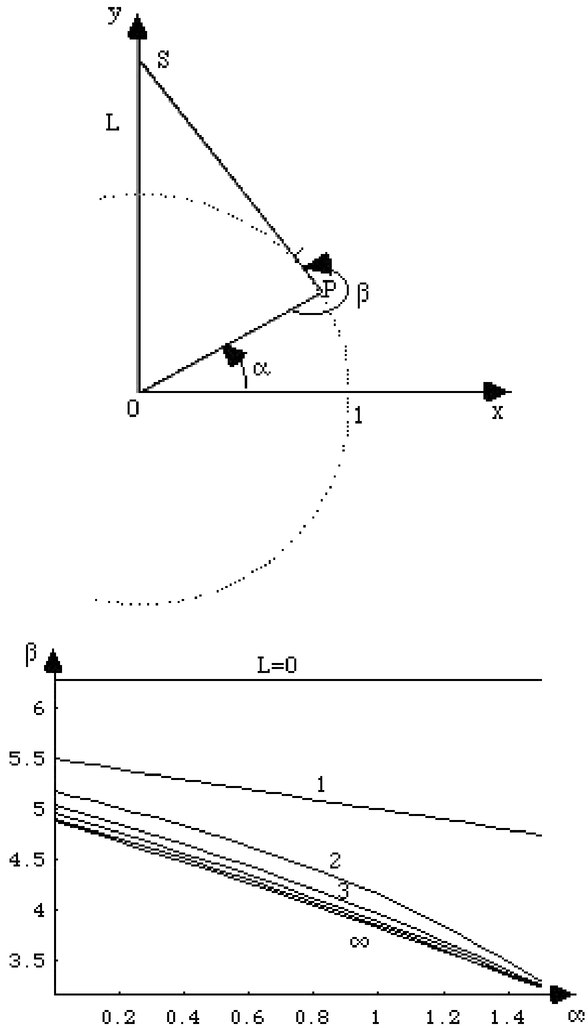

Figure 6. Figure from Lenay et al. (1997) showing the sensorimotor contingency for a simple photocell mounted on an arm and a forearm, in the case where the photocell is continuously fixating a luminous source at distance L. **A:** The arm (with the forearm) has a length of 1. The distance from the target, L (0S), can then be obtained by a trigonometrical relation, according to the following formula: (1) $L = \sin\alpha - \cos\alpha \tan(\alpha + \beta)$, where α: $[0, \pi/2]$ and β: $[3\pi/2 - a, 2\pi]$. **B:** Curve representing angle β in relation to angle α (both expressed in radians) for the following values of $L = 0,1, \ldots 7$. α varies from 0 to $\pi/2$. According to (1) one can determine β for any given L and α: $\beta = 2\pi - \alpha + \text{Atan}((\sin\alpha - L)/\cos\alpha)$.

day with the viola under his chin, on one occasion he went into the kitchen to drink some hot tea, and some drops fell on the viola. He said he was surprised not to have felt the hot drops on the instrument: it felt anesthetized. Another everyday example of remote tactile sensing occurs when you write on a piece of paper with a pen: you feel the paper at the end of the pen: it is rough, it is smooth, it is soft. You locate the contact at the end of the pen, not on your fingers where the force is actually felt (this example is given by James 1890/1950).

One might consider these examples as surprising at first sight. But then we ask: should it not also be considered surprising that fingertip sensations are felt *on the fingertips,* since after all, it is presumably in the brain where the sensations are registered? Why would one not tend to think that one should be able to walk through a door no wider than one's brain, since body sensations presumable arrive in the brain? Indeed, given that visual sensation impregnates the retina, why does one not feel the outside world as situated on one's retina, instead of outside one? These obviously ridiculous extensions of the "relocation" idea discussed above make one realize that, actually, the perceived location of a sensation cannot be logically determined by where the nerves come from or where they go to. Perceived location is, like other aspects of sensation, an abstraction that the brain has deduced from the structure of the sensorimotor contingencies that govern the sensation.[36]

Some very interesting experiments of Tastevin (1937) are related to these points. Tastevin had shown that the sensed identity or position of a limb can be transferred to another limb or to a plaster model of the limb. Thus, for example, when an experimenter feigns to touch a subject's forefinger with one prong of a compass, but actually touches the middle finger with the other prong, the subject feels the touch on the forefinger. Sensation has thus been relocated from the middle finger to the forefinger. Whole body parts can be relocalized by this means. A recent experiment along very similar lines was described by Botvinick and Cohen (1998; and also extended by Ramachandran & Blakeslee 1998). These authors used a life-size rubber model of a left arm placed before a subject whose real left arm was hidden by a screen. Using two small brushes, the experimenters synchronously stroked corresponding positions of the rubber and real arm. After ten minutes, subjects came to feel that the rubber arm was their own.

All these phenomena show how labile the perceived location of a stimulation can be, and how it depends on correlation with information from other modalities (in this case vision). Even neural representations of body parts are known to be labile, as has been shown by Iriki et al. (1996) whose macaque monkeys' bimodal visual somatosensory receptive fields moved from their hands to the ends of a rake they used as a tool. However, a facile interpretation of such phenomena in terms of "neural plasticity" of cortical maps would be misleading, since such an interpretation would implicitly assume that perceived location of a stimulus is directly related to activity in cortical maps – an idea we reject.

5.14. Tactile visual sensory substitution

Tactile visual substitution systems (TVSS) use an array of vibratory or electrical cutaneous stimulators to represent the luminance distribution captured by a TV camera on some skin area, such as the back, the abdomen, the forehead or the fingertip. For technical reasons and because of the restrictions on tactile acuity, TVSS devices have up to now suffered from very poor spatial resolution, generally having stimulator arrays of not more than 20×20 stimulators at the very best. They have also been bulky, expensive, and too sensitive to light level variations, for them to be of practical use by the blind (Bach-y-Rita 1983; Easton 1992). Notwithstanding these problems, however, as concerns the question of visual experience, a number of highly interesting points have been made about the experiences of individuals who have used these devices (Apkarian 1983; Guarniero 1977; 1974).

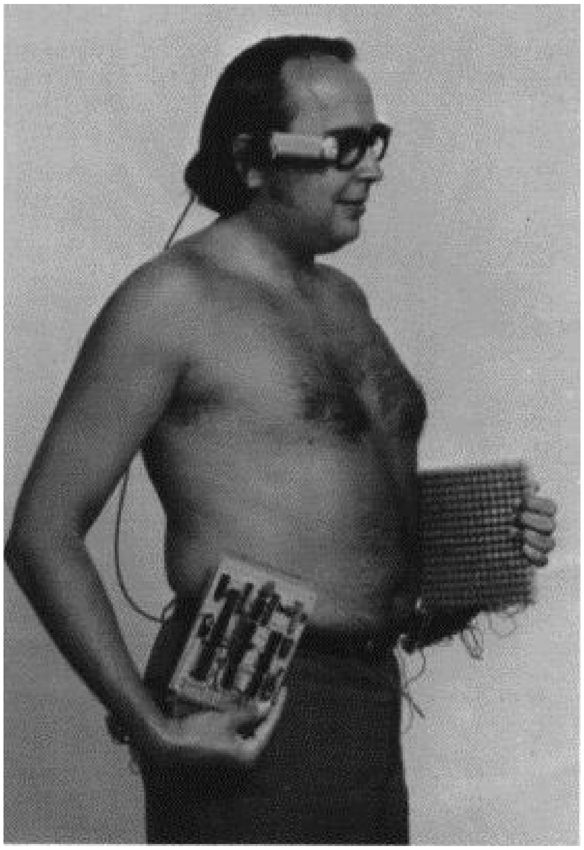

Figure 7. A blind subject with a "Tactile Visual Substitution system" (TVSS). A TV camera (mounted on spectacle frames) sends signals through electronic circuitry (displayed in right hand) to an array of small vibrators (left hand) which is strapped against the subject's skin. The pattern of tactile sitmulation corresponds roughly to a greatly enlarged visual image. (Photograph courtesy of P. Bach-y-Rita). From Morgan (1977).

A first point concerns the importance of the observer's being able to manipulate the TV camera himself or herself (Bach-y-Rita 1972; 1984; Sampaio 1995).

In the earliest trials with the TVSS device, blind subjects generally unsuccessfully attempted to identify objects that were placed in front of the camera, which was fixed. It was only when the observer was allowed to actively manipulate the camera that identification became possible and observers came to "see" objects as being externally localized (White et al. 1970). This important point constitutes an empirical verification of the mainstay of the present theory of visual experience, namely, that seeing constitutes the ability to actively modify sensory impressions in certain law-obeying ways.

Once observers have had practice with the TVSS, several further aspects of the experience provided by the system suggest that it is similar to the experience of vision. First, though initially observers locate stimulation on the body part which is stimulated, with practice, the observers locate objects in space, and not on the skin – although they are still able to feel the local tactile sensation (e.g., if it is painful or if it itches). Indeed, after using one skin location (e.g., the back), an observer has no problem transferring to a different skin location (e.g., the forehead).

An interesting example shows that the localization of objects outside the body is not just a cognitive strategy but truly resembles visual experience. In an anecdote reported by Bach-y-Rita, the zoom control of the camera being used by a well-trained subject was moved, causing a sudden magnification or "looming" of the tactile image. Bach-y-Rita states (1972, p. 98): "the startled subject raised his arms and threw his head backward to avoid the 'approaching' object. It is noteworthy that, although the stimulus array was, at the time, on the subject's back, he moved *backward* and raised his arms in front to avoid the object, which was subjectively located in the three-dimensional space before him."[37] Another interesting observation caused puzzlement in the early investigations with the TVSS. For practical reasons the battery of 400 vibrators mounted on the observer's back consisted of two ramps of 200 vibrators, one on each side of the observer's backbone. A large gap was therefore present in the tactile representation of the visual field. "Curiously" however, no gap was apparent in observers' perceived visual field. This tactile analog of what might incorrectly be called "filling-in" of the retinal blind spot is, of course, unsurprising in the light of the present theory, where no filling-in mechanism need be postulated (cf. sect. 5.5).

Do blind people actually see with the TVSS? The question has been raised by Bach-y-Rita who prefers to put the word "see" in quotes. One justification for this, he claims, is the fact that people who have learnt to see with the device are disappointed when shown pictures of their loved ones, or erotic pictures: they have no emotional reaction. Bach-y-Rita interprets this as a failure of the device to provide true visual experience. An alternative, however, is to admit that the device does provide true visual experience, but that emotional and sexual reactions are strongly linked to the sensations that are experienced during the period when emotional attachment occurs and sexual interest develops. If, during the course of development, these experiences are initially non-visual, then they will remain non-visual.[38]

Morgan (1977) also discusses this and concludes, that either people really do see with the TVSS, or there can be no scientific psychology. Clearly from the point of view of the present theory, seeing is not a matter of "all or nothing." There are many aspects to seeing, and the TVSS provides some but not all of them. The invariants related to position and size changes of the tactile image are similar to those in normal vision. Color and stereo vision however are absent, and resolution is extremely poor. But, just as color blind, stereo blind, one-eyed or low-sighted people can be said to "see," people using the TVSS should also be said to see. The fact that stimulation is provided through the skin should be irrelevant, providing the stimulation obeys the required sensorimotor laws. Of course, seeing with the skin probably involves laws that are not exactly the same as seeing with the eyes, just as seeing colors in the dark is not quite the same as in the light. The experience associated with the TVSS will thus also be somewhat different from normal visual experience.

5.15. The "facial vision" of the blind

A further interesting example of sensory substitution comes from what is called the "facial vision," or "obstacle sense," or "pressure sense" of blind people. In locating objects, particularly when these are large and in the 30–80 cm range, blind people often have the impression of a slight touch on their forehead, cheeks, and sometimes chest, as though they were being touched by a fine veil or cobweb (James 1890/1950; Kohler 1967).

For instance, consider the following quote given by James (1890/1950) from the blind author of a treatise on blindness of the time:

> Whether within a house or in the open air, whether walking or standing still, I can tell, although quite blind, when I am opposite an object, and can perceive whether it be tall or short, slender or bulky. I can also detect whether it be a solitary object or a continuous fence; whether it be a close fence or composed of open rails, and often whether it be a wooden fence, a brick or stone wall, or a quick-set hedge. . . . The currents of air can have nothing to do with this power, as the state of the wind does not directly affect it; the sense of hearing has nothing to do with it, as when snow lies thickly on the ground objects are more distinct, although the footfall cannot be heard. I seem to perceive objects through the skin of my face, and to have the impressions immediately transmitted to the brain. (Vol. 2, p. 204).

At least since Diderot's "Letter on the blind," facial vision had often been considered to truly be a kind of tactile, or even possibly an extrasensory, form of perception (cf. historical review by Hayes 1935, cited by Rice 1966). James (1890/1950, Vol 2, pp. 140, 204) compares this sense to what he believes is a tactile, pressure-related "tympanic sense," that is, the ability we all have of sensing with closed eyes whether an object brought before our face is large or small, or more or less solid. Despite such claims, however, by stopping up the ears of blind people with putty, James demonstrated to his satisfaction that audition was involved in the facial sense. This was then definitively established by Dallenbach et al. (1944), and facial vision is now known to be essentially caused by intensity, direction, and frequency shifts of reflected sounds (see review by Arias 1996). Kohler (1967) actually went so far as to anesthetize the faces of blind people, who nevertheless continued to have these sensations.

As noted by Worchel et al. (1950; cited by Strelow & Brabyn 1982), the question arises why this form of object perception is experienced as having a tactile feeling rather than an auditory quality. A possibility along behaviorist lines has been suggested by Taylor (1962), who supposes that collisions with obstacles will often involve the face – the hands may often rise and protect the face. This may create, by association, feelings on the face in the case of impeding collisions. Further correlations (apparently not mentioned by Taylor) might be the fact that objects that are close to the face tend to provoke slight disturbances of the air as well as changes in heat radiation that could be detected by receptors on the face. Although Taylor's associationist hypothesis may have some truth in it, from the point of view of the present theory another possibility arises: the prediction would be that the sensorimotor contingencies created by the particular, very subtle information received through the auditory modality would, in this particular case, have an invariance structure that resembles the contingencies caused by tactile stimuli, like those created by a veil upon the face.

Indeed, it appears conceivable that the object sense, requiring more subtle auditory distinctions, would be much more critically dependent on distance than normal hearing. In particular, moving a few centimeters forward or backwards, might create a radical change analogous to moving a few centimeters forward or backwards and bringing the head into and out of contact with a veil. Similarly, it may be that when the head is facing the object that is being sensed, slight sideways shifts of the head might create systematic changes similar to the systematic rubbing that occurs when one is touching a piece of cloth with the head. Note, however, that it would be exaggerated to take too literally the comparison that blind people make with veils and cobwebs: Kohler has verified that when touched with actual veils the same blind people say that the sensations are actually quite different. Perhaps the inability to specify precisely the nature of the experience produced prompted the author cited by James to say that the impressions were "immediately transmitted to the brain."

The facial sense of the blind may be related to the phenomenon of synesthesia (Cytowic & Wood 1982; Baron-Cohen & Harrison 1996),[39] where a stimulus in one sensory modality evokes sensations in another, the most frequently occurring case being colored hearing (Marks 1978). Ventriloquism is another type of example where information from one sensory modality modifies that in another: in "visual capture" or the "ventriloquism effect," the perceived location of a sound source is influenced by its seen position, and, to a lesser extent, vice versa (Hatwell 1986; Radeau & Bertelson 1974; Warren et al. 1981). A related phenomenon is the McGurk effect (McGurk & MacDonald 1976) in which the identity of a heard phoneme is altered by simultaneously observing a visual display of a different phoneme being pronounced. Radeau (1997; cf. also Marks 1978) has reviewed a number of inter-sensory interactions such as these, both in humans and animals, and concludes that such effects are compatible with the notion that the different qualities of the senses are not present ab initio, as Piaget might have claimed, but rather (following Gibson 1966; Bower 1979) are the result of a progressive differentiation process that occurs in the developing organism through the influence of environmental experience.

The view taken within the context of the present theory regarding all such intermodal interactions would be related to the above. More precisely, however, it would say that the experience associated with a modality exists only within the context of the acting organism, and within the context of the other senses available to the organism. Although vision, audition, touch, and so on, will have their own specificities due to the particularities of the sensors and sensorimotor contingencies involved – with these specificities defining the particular experience associated with each sense, – interactions between the senses are to be expected when there are systematic correlations and common sensorimotor contingencies.[40] Perceptual adaptation effects like the McCollough effect (Harris 1980; Humphrey et al. 1994; McCollough 1965a; 1965b) and the related disappearance of color fringes on adaptation to displacing prisms (Held 1980; Kohler 1951) may be manifestations of similar nature, except that they are intramodal rather than intermodal.

6. Visual consciousness

6.1. Introduction

The sensorimotor contingency theory of vision we have developed here provides a new vantage point from which to approach the vexing theoretical question of the nature of visual consciousness. Vision, we have argued, is a mode of skillful encounter with the environment, requiring knowledge of sensorimotor contingencies and also the ability to make use of that knowledge for the purpose of guiding action, thought, and (in humans) language use. What, in this view, is visual consciousness?

6.2. Two kinds of visual consciousness

We propose to distinguish between two kinds of visual consciousness: (1) *transitive visual consciousness* or *consciousness of;* and (2) visual consciousness in general.

(1) To be *transitively conscious* is to be conscious *of* a feature of a scene (Malcolm 1984). To be conscious of a feature of a scene in this sense is simply to be visually aware of it, as laid out in section 2.6.

Thus, to say that you are transitively conscious of (for example) the shape of a parked car in front of you is to say that you are, first, currently exercising mastery of the laws of sensorimotor contingency that pertain to information about the shape of the car; and, second, that you are attending to this exercise, in the sense that you are integrating it into your current planning, reasoning, and speech behavior.

Notice that when you are visually conscious of the shape of the car, you may fail to attend to its color, or to the fact that the object in front of you *is* a car. As you shift your attention from one aspect of the car to another, features of the car enter consciousness. What happens when you thus shift your attention is that you draw into play different bits of implicit knowledge of the relevant sensorimotor contingencies.

To this, it might be objected that when you look at the car, you have the impression that all its details are available in consciousness all at once. In looking at the car, you are conscious of, or aware of, its shape, color, nature, and so on, all in a glance. But this objection is easily countered. First, the empirical data on change blindness (see sect. 5.10 above) and inattentional blindness (see Noë & O'Regan 2000) demonstrate that you do *not* have all the details of what is seen in consciousness at once. The actual case is that all the detail is there in the scene in front of you and is thus accessible by the slightest effort. Second, and of great importance, is that your *feeling* of the presence of all the detail consists precisely in your knowledge that you can access all this information by movements and inquiries.

(2) *Visual consciousness in general,* on the other hand, is a higher-order capacity. To be visually conscious in general is to be poised to become aware of a present feature (that is, to become transitively conscious of it). In this sense of visual consciousness, we can contrast *being visually conscious* with being asleep or with being blind. Consciousness in this most general sense consists in one's possession of the ability to become *conscious of* aspects of a scene (that is, in one's ability to see, to explore aspects of the environment in a fashion mediated by the relevant sensorimotor contingencies).

6.3. The problem of qualia

As noted above in section 2.7, it may be argued that there is still something missing in the present account of vision, namely, an explanation of the *qualitative character* of visual experience. Can the sensorimotor contingency theory in addition provide an explanation of what philosophers have called "the raw feel" or "qualia" of seeing?

"Quale" is a technical term in philosophy. Like most such terms, to become clear about its precise meaning is to enter into the throes of philosophical controversy. Qualia are frequently characterized as the "phenomenal," or "qualitative," or "intrinsic" properties of experience, and they are typically contrasted with "intentional," or "representational," or "functional" features. Qualia are said to be that thanks to which there is something that it is like to have an experience (something that is, in addition, independent of representational or functional features). One of the central philosophical debates surrounding qualia concerns the question whether qualia can be studied by means of traditional biological and cognitive science. It has been suggested on this point that there is an unbridgeable "explanatory gap," that it is not possible to explain the subjective, felt aspects of experience in behavioral, physical, or functional terms.

In our view, the qualia debate rests on what Ryle (1949/1990) called a category mistake. Qualia are meant to be properties of experiential states or events. But experiences, we have argued, are not states. They are ways of acting. They are things we do. There is no introspectibly available property determining the character of one's experiential states, for there are no such states. Hence, there are, in this sense at least, no (visual) qualia. Qualia are an illusion, and the explanatory gap is no real gap at all.

It is important to stress that in saying this we are not denying that experience has a qualitative character. We have already said a good deal about the qualitative character of experience and how it is constituted by the character of the sensorimotor contingencies at play when we perceive. (We have more to say about this below; see also the discussion of the individuation of sensory modalities in sect. 2.5). Our claim, rather, is that it is confused to think of the qualitative character of experience in terms of the *occurrence* of something (whether in the mind or brain). Experience is something we do and its qualitative features are aspects of this activity.[41]

6.4. What gives rise to the illusion of qualia?

Many philosophers, vision scientists, and lay people will say that seeing always involves the occurrence of raw feels or qualia. If this view is mistaken, as we believe, then how can we explain its apparent plausibility to so many? In order to make our case convincing, we must address this question.

In our view, there are two main sources of the illusion. The first pertains to the unity and complexity of experience. We tend to overlook the complexity and heterogeneity of experience, and this makes it seem as if in experience there are *unified sensation-like* occurrences. The second source of illusion has to do with the *felt presence* of perceptible qualities. Because, when we see, we have continuous access to features of a scene, it is *as if* we continuously represent those features in consciousness. We elaborate these two mistaken lines of reasoning in turn.

6.4.1. The unity of experience. Scientists and philosophers frequently get the phenomenology of experience wrong; they misdescribe what perceptual experience is like. Consider, as an example, the experience of driving a Porsche and its distinctive qualitative character. What does this feeling consist of? What is it like? Notice that, in one sense, there is no feeling of Porsche-driving. That is, the character of Porsche-driving does not consist in the occurrence of a special sort of momentary flutter or bodily sensation.

What defines the character of driving a Porsche, rather, is something more complex. There are characteristic ways in which the vehicle accelerates in response to pressure on the gas pedal. There are definite features of the way the car handles turns, how smoothly one can change gears, and so on. What it is like to drive a Porsche is constituted by all these sensorimotor contingencies and by one's skillful mastery of them, – one's confident knowledge of how the car will respond to manipulations of its instruments.[42]

In one sense, then, there is no Porsche-driving quale. After all, what it is like to drive a Porsche depends on these various activities. In another sense, however, one can speak of the qualitative character of driving a Porsche, but this must be understood not in terms of the occurrence of a sensation-like quale in the mind, but rather, in terms of one's comfortable exercise of one's knowledge of the sensorimotor contingencies governing the behavior of the car.

We propose that the same account can be extended to such prototypical visual qualia as "the raw feel of a shade of red." Suppose you stand before a red wall. It fills up your field of view. What is it like for you to see this red wall? Try to describe the experience. How do you fulfill this instruction? One thing you might do is direct your attention to one aspect or another of the wall's redness. For example, you might focus on its hue, or its brightness. In this way you become transitively conscious of (that is to say, *aware of*) this or that aspect of the wall's color. How do you accomplish this? In what does your focusing on the red hue of the wall consist? It consists in the (implicit) knowledge associated with seeing redness: the knowledge that if you were to move your eyes, there would be changes in the incoming information that are typical of sampling with the eye; typical of the nonhomogeneous way the retina samples color; knowledge that if you were to move your eyes around, there might be changes in the incoming information typical of what happens when illumination is uneven, and so on. Importantly, there is not *one* thing in which the focussing of your attention on the hue (say) consists. Eye movements, shifts of attention, the application of understanding – seeing the red hue of the wall consists in all of this. There is no simple, unanalyzable core of the experience. There are just the different things we do when we see the redness of the wall.

In one sense, then, we can say that there is no red-quale (just as there is, in a sense, no Porsche-driving quale). An experience of a red surface is not a sensation-like occurrence. Seeing something red is a variegated activity, and to describe its character adequately, one must describe the many different things we do when we see something red.

6.4.2. The felt presence of qualities. Let us now turn to the second source of the illusion of qualia. Consider once again the phenomenon of change blindness. Many people say that they have the impression that when they see, the entire visual field is present to consciousness in all its nearly infinite detail. However, the change blindness results suggest that we do not have such detailed, picture-like awareness. What explains the conviction that we do? As we have discussed above, and as argued by O'Regan (1992; cf. also O'Regan et al. 1999), the explanation is that we have access to all the detail by means of the mere flick of an eye or turn of the head, and so it is *as if* we had everything in view all the time. The *feeling* of the presence of detail stems from our implicit knowledge of the ways in which movements of the eye and head gives rise to new detail and new information. Importantly, one can explain this feeling without supposing that all the detail is represented in consciousness.

In exactly this way, when we see something red we *feel* that the redness has a certain definite, sensation-like presence and immediacy. The explanation for this is that we have access to the redness by the most minute of eye movements or attentional shifts. The redness is there, in the environment. The slightest eye, head, or attention movement reveals further information about its character. Because we have continuous *access* to the redness in the environment, it may seem as if we are mentally in contact with it continuously. This leads us to say, mistakenly, that there is a feeling of redness (say) in our heads all along.

6.5. Is the illusion of qualia really so widespread?

Is the illusion of qualia really as widespread as it would seem? Perhaps not. If you ask what a person sees, he or she will not bring up visual experiences and their intrinsic features. In everyday life, discussions of what we see are for the most part confined to discussions of things themselves (of the things we see). Even when we are viewing a piece of art, when we may deliberately try to reflect on the way the work affects us visually, nonphilosophers will rarely confuse the question *what it is like to look at the piece* (what it reminds one of, how it makes one feel, whether one finds it pleasant, or not) with that favorite question of philosophers, namely, *what is it like to have an experience as of seeing a painting* (that is, what are the intrinsic, qualitative features of the visual experience)?

Another way to put this point is to say that qualia-based accounts of the phenomenology of experience actually misdescribe the phenomenological character of experience (what experience is like). Qualia-talk, one might say, is theory driven and the illusion of qualia is a theoretical illusion. Crucially, normal perceivers do not, by virtue of being normal perceivers, buy into the relevant theory.

6.6. The ineffability of the qualitative character of experience

We have proposed that experience is a temporally extended activity of exploration mediated by the perceiver's knowledge of sensorimotor contingencies. The differences in the qualitative character of perceptual experiences correspond to differences in the character of the relevant sensorimotor contingencies. Just as the difference between driving a Porsche and driving a tank consists in the different things you do in driving it – that is, in the different skill-based understanding of how to drive the vehicle, – so the difference between seeing a red flower and smelling a red flower consists in the different patterns of sensorimotor contingency governing one's perceptual encounter in each situation. To experience a red object, or the feel of driving a Porsche, is to know, for example, that if you change the illumination in such and such ways (or press down on the accelerator in such and such ways), it will produce such and such changes in the stimulation.

It follows, according to this view, that to reflect on the character of one's experience is to reflect on the character of one's law-governed exploration of the environment, on what one does in seeing. Some of the sensorimotor contingencies governing vision are easily accessible to awareness. If you reflect on the character of your visual experience of a colorful flower, for example, it is easy to comprehend the manner in which the appearance of the flower is a function of viewing angle and illumination. If you look at a plate and turn it, you can become aware of the way its profile becomes elliptical. If you put on inverting lenses, it is immediately apparent that eye and head movements produce surprising patterns, thus enabling us to direct our attention to the disruption of familiar patterns of sensorimotor contingency. But though we have access to these aspects of the sensorimotor contingencies, there are other components of the sensorimotor contingencies which do not lend themselves easily to propositional description, and which are not so easily brought into consciousness: the exact laws that the flower's color obeys when you change the illumination, the exact rule determining the modification of the plate's profile, the precise disruption caused by distorting lenses. Other examples even less accessible to consciousness are: the particular way the macular pigment and the non-homogeneity of retinal sampling affect sensory input when the eye moves; the optic flow that occurs when the head rotates, and so on.

We believe that these considerations enable us to get clear about a feature of experience that has often provoked puzzlement on the part of scientists and philosophers, namely, its apparent ineffability. It is very difficult to describe everything we do when we see, just as it is difficult to describe everything we do when we are engaged in other skillful activities such as athletic endeavors, playing an instrument, or speaking a language. A major portion of our mastery of sensorimotor contingencies takes the form of practical know-how. When we attempt to inquire into the more subtle features of what goes on when we perceive, we immediately come up against the fact that it is very difficult to describe any but the most high-level, gross sensorimotor contingencies.

There is nothing mysterious about this inability. In general, the ability to know how to do something does not carry with it the ability to reflect on what it is one does when exercising the ability in question. The difficulty in describing the character of experience is not evidence of the special character of experience in the world order. But it does bring forcibly to mind the fact that experiences are "exercisings" of complicated capacities, not ongoing occurrences in the mind or brain.

6.7. On the possibility of phenomenology

We hope it is clear that it is no part of our argument to deny the possibility of, or the importance of, phenomenological reflection on experience.[43] Indeed, we believe that our view provides an account of the subject matter of phenomenology that is superior to that put forward by qualia-oriented positions.

First, our theory is supported by careful reflection on what it is like to have perceptual experience. It is commonly asserted by both philosophers and scientists, that it seems to normal perceivers as if perception involves detailed internal representations of the environment in the head. As noted in section 4.2, we believe this misdescribes the character of seeing. First of all, in seeing we commit ourselves to no beliefs about what is going on in our heads. Seeing is directed to the world, not the brain. Second, when we see, we take the perceived detail to be out there in the world, not in our head. Indeed, we take ourselves to be embedded in the environment and to have access to detail through active exploration. In our view, it is just bad phenomenology to assert that we take ourselves to have a 3D-model or picture in the head when we see. In short, we believe that, once it has broken free of clichés about pictures in the head, phenomenological reflection on the character of experience does support the kind of approach developed here.

Second, traditional qualia-based approaches to experience threaten to make experience itself something mysterious and inaccessible. However, the subject matter of phenomenological reflection is not an ephemeral, ineffable, sensation-like momentary occurrence in the mind, but, rather, the real-world, temporally extended activity of exploring the environment and the structure of sensorimotor contingencies. There is a qualitative or phenomenological difference between seeing and hearing and touching, as stated. These are different activities, corresponding to different modes of exploration of the structure of sensory-motor contingencies. To see a bottle, for example, is to explore visual-motor contingencies, such as transformations in the appearance of the bottle as one moves in relation to it. To touch it, on the other hand, is to explore the structure of tactile-motor contingencies. The bottle impedes, guides, and informs tactile exploration of the bottle. To reflect, then, on what it is like to see the bottle, or to touch it, is to reflect on just these sorts of facts about the active engagement the perceiver undertakes with the environment (see Noë 2001). In this way, we believe that the kind of approach we lay out in this paper helps place phenomenology as an undertaking on solid ground (see Noë 2002, for a development of this idea).

6.8. Overcoming the explanatory gap (or, Why there is no gap)

As noted above, the problem of the explanatory gap is that of explaining qualia in physical or biological terms. We believe that our view bridges this gap. More accurately, it demonstrates that the gap itself is an artifact of a certain – we believe mistaken – conception of experience. There is not really any gap at all.

Our claim, simply put, is this: there is no explanatory gap because there is nothing answering to the theorist's notion of qualia. That is, we reject the conception of experience that is presupposed by the problem of the explanatory gap. (Note that we can make this claim even though we do not deny, as we have been at pains to explain above, that there are experiences and that experience has qualitative character.)

To appreciate the structure of our claim, consider once again, very briefly, the Porsche-driving example. We have argued that the feeling of driving a Porsche derives from the different things we do when we drive a Porsche, and from our confident mastery of the relevant sensorimotor contingencies. We can now appreciate that there is no need to explain the physical or causal basis of the occurrence of the unitary Porsche-driving quality, for there is no such quality. What does need to be explained is the physical (neural) basis of the various component skills that are drawn into play when one drives a Porsche (for it is these that constitute the feeling). And so, likewise, there is no need to seek a neural basis for the occurrence of visual qualia such as that of red, for, in the relevant sense, there are no such qualia.

To this it will be objected that it is no more easy to see how possession and mastery of sensorimotor skills is to bridge the explanatory gap, than it is to see how different patterns of neural activity can accomplish the same feat. But this very question betrays a failure to understand our proposal. For our claim is *not* that knowledge and exercise of sensorimotor contingencies can solve the same feat. Our claim is that there is no feat to be accomplished and, *therefore,* no possible way in which neural activity can accomplish it. Let's return again to simple examples. You hold a bottle in your hand. You *feel* the whole bottle. But you only make contact with isolated parts of its surface with isolated parts of the surface of your hands. But don't you feel the whole bottle as present? That is, phenomenologically speaking, the feeling of presence of the bottle is not a *conjecture* or an *inference.* The feeling you have is the knowledge that movements of the hand open up and reveal new aspects of bottle surface. It feels to you as if there's stuff there to be touched by movement of the hands. That's what the feeling of the presence of the bottle consists in. But the basis of the feeling, then, is not something occurring now. The basis rather is one's knowledge *now* as to what one can do.

6.9. Summary

Let us summarize the main claims of this section.

(1) There are two kinds of visual consciousness. There is transitive visual consciousness (or *consciousness of*), which consists in one's awareness of an aspect of a scene. There is *visual consciousness in general,* which consists in one's general capacity to become aware of different features of the scene. Transitive consciousness, as a form of awareness, can be explained just as we explain visual awareness in section 2.6 above. To be aware of a feature is to exercise one's practical knowledge of the relevant sensorimotor contingencies. Visual consciousness in general is just the higher-order capacity to exercise such mastery.

(2) The difference between different perceptual experiences, and between different perceptual experiences in different sensory modalities, can be explained in terms of the different things we do in having the experience and in terms of the different rules of sensorimotor contingency that are invoked in each case. The supposition that there are further qualitative aspects of experience that cannot be explained along such lines is an illusion, engendered by: (a) our tendency to fail to attend to the heterogeneity and complexity of experience; (b) our tendency to treat continuous access to environmental detail as the continuous representation of that detail. Moreover, we claim that the illusion of qualia is actually not as widespread as philosophers often suggest, and that the conception of experience we develop in this paper – experience as a mode of skillful activity – is actually truer to the actual character of felt experience than qualia based views.

(3) There is no explanatory gap. We do *not* claim that it is possible to explain the physical basis of conscious experience by appeal to sensorimotor contingencies. How, one might ask, can sensorimotor contingencies explain phenomenal consciousness any better than other proposals that have been made? Rather, we argue, as should by now be clear, that the conception of phenomenal consciousness itself must be (and can be) rejected, and so there is no longer any puzzle about how to explain that. As we make clear in the points above, other aspects of consciousness can indeed be explained according to our view.

We have not attempted to present solutions to such philosophical chestnuts as the problem of undetectable spectrum inversion, or the problem of zombies. Instead, we have turned our attention to the presentation of a framework within which to investigate the nature of vision and visual consciousness. We have drawn attention to the wealth of empirical data that support our theory. In addition, we have tried to provide some statement of what we take to be the implications of this view for progress on the topic of visual consciousness. We have adopted the strategy of trying to demonstrate the fruitfulness of our approach instead of that of refuting the philosophical opposition. This sort of indirect approach is necessary when what divides camps is not so much disputes over what the facts are, but rather, fairly messy questions about how to make sense of the interdependence of a whole network of related ideas: seeing, vision, visual experience, visual consciousness, qualia, raw feel, awareness, and attention. We have made a number of proposals about how to think about this raft of interconnected phenomena which will, we hope, allow for empirical progress.

7. Philosophical niceties

7.1. Awareness versus consciousness

Chalmers (1996a) distinguishes between awareness and consciousness. Awareness, according to Chalmers, is a state in which some information (that of which we are aware) is available for control of behavior and for guiding verbal report. Consciousness, or *experience,* on the other hand, is an intrinsically qualitative state whose links to behavior are inessential. Chalmers' distinction is very similar to Block's (1995b) distinction between access-consciousness and phenomenal-consciousness. A state is access-conscious, according to Block, if it is poised to be used to govern rational thought, guide behavior, or give rise to verbal report. A state is phenomenally conscious, however, if it *is an experience.* Block and Chalmers agree that awareness (or A-consciousness) is a functional notion, definable in terms of behavior and dispositions to behave, and they agree that consciousness (or P-consciousness, or experience) are non-functional notions (that is, functional duplicates can differ in their P-consciousness). (Block and Chalmers differ in important details that do not concern us here.)

We are skeptics about phenomenal consciousness understood the way Block and Chalmers understand it. As we stated above, what explains the illusion that seeing consists in the occurrence of an *internal qualitative state* is the fact that, at any moment, one can direct one's attention to one's activity of looking and so encounter such qualities as the redness of a wall, or the distinctive shape of a seen object. Moreover, we are able to track not only objects of awareness, but our tracking activity itself and thus become aware (in the functional sense) of the percepts induced by the patterns of sensorimotor contingency governing our seeing. The experience of red, for example, arises when we know (though this is not propositional, but rather, practical knowledge) that, for example, if we move our eyes over a red region, there will occur changes typical of what happens when our non-homogeneously sampling retinas move over things whose color is red. It is, then, our continuous *access* to the redness that provides the key to understanding why it (mistakenly) seems to us as if we are continuously undergoing experience as of something red.

Our account of seeing and visual awareness thus cuts across the distinction between awareness and consciousness (as Chalmers puts it), or between A- and P-consciousness (in Block's terms). Visual experience is a matter of access, but access to the world, and to one's activity of tracking and interacting with the surrounding scene, not to one's internal information-bearing states. The felt or qualitative character of seeing is to be explained in terms of this active conception.

7.2. Blindsight

Block (1995b) puts the concepts of A- and P-consciousness to work in his discussion of blindsight. Patients with blindsight have suffered lesions in the visual cortex as a consequence of which they appear to be blind in a region of the visual field (Pöppel et al. 1973; Weiskrantz 1986). Subjects report that they see nothing when a stimulus is presented to their scotoma. When asked to guess (from a number of choices) what is present in their blind field, subjects are correct at a rate well above chance. There would seem to be a sense, then, in which these individuals see without seeing. One possibility is that these patients see, but are unconscious of seeing. This in turn suggests that the function of consciousness is to enable us to make use of the information we acquire. Block (1995b) attacks this reasoning because it fails to distinguish between A- and P-consciousness. P-consciousness is surely lacking, but A-consciousness is absent too, at least for the most part. One is not entitled, then, to draw general conclusions about consciousness from the phenomenon of blindsight.

Block contrasts blindsight with a nonactual but, he thinks, conceptually possible phenomenon of superblindsight. In superblindsight, as Block describes it, subjects have apparently normal access to information acquired in their blind fields, but they lack *experience* of the information. He invites us to imagine that these individuals have been trained to trust their "guesses" about what is present in their blind fields. This information, therefore, is available to guide action and speech. Indeed, we are asked to imagine that, as far as speech and behavior go, people with superblindsight seem normal. There is one noteworthy exception, of course. If you ask them whether they visually experience what is present in their blind field, the way they experience what is present to their non-blind field, they reply that they experience nothing. They are as good as blind as far as feeling goes.

Block's main contention then is two-fold: (1) that superblindsight is visual A-consciousness in the absence of P-consciousness; and (2) that superblindsight is conceptually possible. We doubt both points. As for (1), it seems that we have grounds for doubting that the patient really has a blind field. After all, the patient appears to see just fine. As Dennett (1995) notes, Block's account appears to trade, illegitimately, on the fact that in actual blindsight the kinds of information involved are remarkably sparse (on this point, see also Noë 1997). The subject is correct, for example, about the orientation of a line grating. But if we imagine informational content to be greatly enriched, as would seem required in the case of superblindsight, then the claim, on the part of the subject, that he lacks P-consciousness, becomes highly implausible. It is difficult to make sense of the claim that a person might offer an accurate description of a painting, say, describing all the colors and the geometry of the composition in a natural manner, all the while having no experience of the painting. One loses all grip on what it could mean to say that the subject *has no experience.* And this indicates the nature of our misgivings about (2). If you are perceptually alert to the presence of environmental detail in a manner that allows you to describe what is present, and if you are sensitive to the appropriate visual laws of sensorimotor contingency (for example, if the detail is no longer accessible when you close your eyes or the lights go out, if the image shifts in the normal way when you move your eyes, if your attention is immediately drawn to any change in the image, etc.), – then surely it would be very peculiar to say that you are not experiencing/seeing the painting (Noë 1997).

Nor do we find Block's (1995b) examples of cases of P-consciousness without A-consciousness convincing. He gives the example of having a conversation while a power drill makes a racket outside the window. One is engrossed in the conversation and one does not notice the drill. All of a sudden one notices it. Block proposes that in a case such as this, insofar as one did hear the drill before noticing it, one was P-conscious of the drill while at the same time A-unconscious of it. When one noticed the drill, one becomes A-conscious of what one had previously heard and been P-conscious of all the time.

But did one hear the drill before one noticed it? The view developed in our paper here requires a negative answer to this question. One does not hear the sound of the drill because one does not make use of one's auditory tracking. This is of course compatible with its being the case that we are sensitive to the sound before we hear it (before we become conscious of it). The auditory system will analyze and store (perhaps only in a short-term memory buffer) information pertaining to the drill. But we do not use that information, nor are we, before we notice the drill, *poised* to use that information or *able* to use that information to guide our behavior, thought, movement, or perceptual exploration.

One might challenge Block's view in another way as well. Consider a slightly different but familiar example. A bell is chiming. All of a sudden you notice not only that there is a bell chiming, but that there were six chimes in all. Surely this shows that you heard the chimes even before you noticed it? Indeed, what this would show, as Chalmers has argued, is that there is a sense in which one *was* in fact *poised* to make use of the unnoticed sounds one was hearing even as one failed to notice them. That is, according to this line of reasoning, one was A-conscious of the unexperienced sounds (contrary to what Block would say).

One virtue of this account is that it perhaps fits somewhat better with ordinary usage of words like "hear" and "see." That is, it seems quite natural to say that you heard the clock chime without noticing it. But there are substantive empirical reasons to reject this account nonetheless. The fact that a stimulus is present and is actively impinging on the senses, does not entail that you perceive it. This is the central upshot of the change blindness studies (discussed in sect. 5.10) and also recent work on so-called "inattentional blindness" (discussed in sect. 5.11). The fact that a stimulus is present means that it is available to be probed by the active animal. Only while the active probe is occurring do you get conscious perception (seeing or hearing, say).

The conflict between our view and that of common sense is actually more apparent than real. As we noted earlier in our discussion of awareness, awareness is a matter of degree. Part of what makes it seem so reasonable to say that you heard the noise without noticing it, or that you (a driver) saw a car without noticing it, is that we may call to mind cases where you are in fact noticing a sound or an object *a little bit.* For example, you are trying to have a conversation and there's that irritating noise in the background which threatens to interrupt you but to which you are paying very little attention. Nevertheless, having said all this, we are quite prepared to bite the bullet and insist that in the complete absence of *current access,* there is no perception.

Note that to say that there is no perception is not to say that there may not be significant *unconscious* influence on behavior or action.[44]

7.3. Our relationship to Dennett

The view developed in this paper is very similar in important respects to the position developed over the last few decades by the philosopher D. C. Dennett (Dennett 1978; 1987; 1991; Dennett & Kinsbourne 1992). But, as the discussion of the previous section suggests, there are important differences as well.

Many philosophers and scientists assume that consciousness is an *intrinsic* property of neural states. The idea is that, among the multitude of content-bearing states in the brain, some subset of states have an additional property of being *phenomenally* conscious. (This is in contrast to states which, in the terminology of Block, are *access*-conscious. This access consciousness is not thought to be an intrinsic property of the state but one that depends on the relation between that state and others in the broader system.) The problem of consciousness, in this general picture, is to understand what processes or mechanisms or events in the brain make certain contents phenomenally conscious. Where, and how, does consciousness happen in the brain?

We reject not only specific attempts to answer this question (oscillations, synchrony, microtubules, etc.), but the assumptions implicit in the question itself. That is, like Dennett, we reject Cartesian materialism (Dennett 1991; Dennett & Kinsbourne 1992). Phenomenal consciousness is not a property of states in what Dennett calls the subpersonal system (i.e., the brain – whether thought of in neural, or in more abstract, cognitive or computational terms) (Dennett 1978; 1969; 1987). There need be no one-to-one correlation between states of consciousness and events in the brain.

But this brings us to the main point of our disagreement with Dennett. Although we reject accounts of phenomenal consciousness as a property of subpersonal states, we do not deny (as we have sought to make clear in the previous sections, especially sect. 6.7), that there are experiences and that there are facts about what experiences are like. But these, however, are facts not about a person's qualia or raw feels. They pertain, rather, to the person's (or animal's) active engagement with the world he or it inhabits.[45] They are facts at the personal (as opposed to subpersonal) level. We return to this point below.

One of the cornerstone's of Dennett's approach to the problem of consciousness, is his conception of *heterophenomenology* (Dennett 1991). In many respects, we are very sympathetic to this approach. The best way to understand what Dennett means by heterophenomenology is to contrast this view with could be called *introspectionism.* Introspectionism is the view that the conscious subject has immediate epistemic access to his or her conscious states. Perhaps not too many writers would endorse introspectionism when put forward in this blunt manner, but it is clear that something like this idea drives a good deal of discussion in contemporary consciousness studies. Theorists believe that we know, on the basis of reflection on our own case, what our own conscious states are like. Dennett rejects introspectionism. Dennett has a lot to say about why introspectionism is untenable, and we are sympathetic to his position. For our purposes it is enough to point out that, according to Dennett, as scientists we cannot assume that subjects are right in their first-personal avowals of conscious experience. Such reports are just further bits of evidence about the nature of mental life and they have no privileged status with respect to other forms of evidence (e.g., psychophysical, neural, psychological, etc.). According to heterophenomenology, then, first-person reports of experience have no special status attached to them. There is no deep and unfathomable asymmetry between what can be known *in the first person,* and what can be known *in the third person.*

Although we endorse Dennett's rejection of naïve introspectionism, our endorsement of the claim that first-person approaches to consciousness are not privileged with respect to third-person approaches is guarded. To appreciate why, consider an example: Dennett (1991) criticizes what he takes to be the widespread assumption, on the part of perceivers, that the visual field is in sharp detail and uniform focus from the center out to the periphery. Simple tests (e.g., the colored pencil test mentioned earlier in sect. 5.6), and well-known facts about the non-homogeneity of the retina, suffice to show that this account of the quality of the visual field is misguided. But is it really true that normal perceivers think of their visual fields this way? Do normal perceivers really make this error? We think not. As noted earlier in connection with change blindness (and see Noë 2001; Noë et al. 2000; and Pessoa et al. 1998), normal perceivers do not have ideological commitments concerning the resolution of the visual field. Rather, they take the world to be solid, dense, detailed, and present, and they take themselves to be embedded in and thus to have access to the world.

The point of this example is that Dennett seems to *mis*-characterize how things seem to perceivers, that is, he mischaracterizes their first-person judgments as to the quality of experience. He does this precisely because he is insufficiently attentive to the actual phenomenology of experience. What this shows is that there are substantive empirical questions about the first-person quality of experience. To investigate such questions, presumably, one must avail oneself of the first-person perspective. From this it does not follow, to be sure, that first-person methods are privileged with respect to third-person methods, but it does follow that it ought to be possible to develop modes of first-person investigation of experience that do not suffer from the flaws of qualia-based (introspectionist) approaches.[46]

The crucial point is that nothing in Dennett's criticisms of naïve introspectionism entails that all first-person approaches to consciousness must take the form of naïve introspectionism, and so nothing in the arguments speaks against the possibility of, or importance of, first person approaches. In the concept of perceptual experience we have endorsed, first-person reflection on the character of experience would not consist in *intro*spection at all, but rather in attentiveness to the complexity of the activity of perceptual exploration. Ironically, as we have seen, Dennett's rejection of the importance of the first-person perspective has led him, at crucial junctures, to *mis*describe the character of perceptual experience.

8. Visual neuroscience

8.1. The brain and vision

Much work on visual neuroscience rests on the idea that for every perceptual state there is a neural correlate sufficient to produce it. In addition, it is widely supposed that the function of this neural substrate is to produce sensory experience by generating a "representation" corresponding to the content of the experience. A very different conception of the role of the brain in vision emerges from the standpoint of the sensorimotor contingency theory.

According to this theory, seeing is a skillful activity whereby one explores the world, drawing on one's mastery of the relevant laws of sensorimotor contingency. Seeing, in this sense, is somewhat like dancing with a partner. Dancing is a complicated activity. There is no *one* thing in which dancing consists and there is no single state of being in the dancing state. Dancing consists in the integration of a range of connected skills: sensitive listening, coordinated movement (or sometimes the *absence* of movement); and, importantly, partner dancing requires the presence of a partner to whose actions and reactions one is appropriately attuned. There is no doubt that neural activity in the brain is necessary to enable one's skillful performance of the dance. But this neural activity is not *sufficient* to produce the dancing. This is so because the accompanying, appropriate actions and reactions of the partner are also needed. These provoke weight changes, disequilibria, rebounds, and so on, which cannot occur without the partner being present, and which are part and parcel of the dancing activity.

In the same way, we argue, seeing also necessarily involves particular forms of action and reaction on the part of the visual apparatus and the environment. The brain enables us to see by subserving the different capacities that get drawn on in the activity of visual exploration. But the brain's activation does not in itself constitute the seeing. In partner dancing, specifying the bodily configuration or brain state of the dancer is not sufficient to specify the dance (because we need additionally to know how the partner is currently interacting). Likewise, in seeing, specifying the brain state is not sufficient to determine the sensory experience, because we need to know how the visual apparatus and the environment are currently interacting. There can therefore be no one-to-one correspondence between visual experience and neural activations. Seeing is not constituted by activation of neural representations. Exactly the same neural state can underlie different experiences, just as the same body position can be part of different dances.

How then are we to understand the role played by the brain in vision? Our proposal, which we develop below, is that the brain supports vision by enabling mastery and exercise of knowledge of sensorimotor contingencies.

8.2. The search for neural representations and the neural correlate of consciousness

Perhaps the most widely cited work which might be thought to constitute evidence for the existence of cortical representations of sensory stimuli could be taken to be the observations of Penfield, who solicited sensory responses from unanesthetized patients undergoing brain stimulation (e.g., Penfield & Jasper 1954). More recent work in visual science and consciousness studies has been devoted to the quest for what has been called "neural correlates of consciousness" (Crick & Koch 1990; 1995; 1998; – for an illuminating review, cf. Chalmers 1996a, Ch. 6). As an illustration of such work, we can use the impressive studies of Logothetis and colleagues (Leopold & Logothetis 1996; Logothetis 1998; Logothetis et al. 1996) analyzing neural substrates of binocular rivalry in laboratory monkeys. In binocular rivalry, each eye is presented with a different stimulus (e.g., a horizontal bar, a face). Under these conditions the observer experiences not both stimuli, or some amalgam of the two, but rather a sequence of alternating percepts corresponding to one or other of the two stimuli. When one stimulus is dominant, the other is not perceived. The perceptual reversals occur irregularly and at intervals of a few seconds. Logothetis and collaborators show that in tested visual areas (e.g., V1/V2, V4, MT, IT, STS), some neurons are unaffected by perceptual reversals. The activity of these neurons is driven by the stimulus patterns entering the eyes, which remain unchanged. The activity of other neurons, however, depends directly on the internally generated shifts in the percept. The percentage of such percept-driven cells is substantially higher in IT and STS – where 90% of tested neurons correlate to percepts, – than in other visual areas. (In V1/V2, for example, a much smaller percentage of neurons were percept-driven.) These data suggest (it is claimed) that neural activity in IT and STS forms the neural correlate of the experience.

Other kinds of neural representations or neural correlates of conscious perceptual experience arise in the context of perceptual completion phenomena. A classical example is the work of von der Heydt and his colleagues, who found neurons in V2 that fire for illusory contours in a very similar way that they fire for real contours (Peterhans & von der Heydt 1989; von der Heydt & Peterhans 1989; von der Heydt et al. 1984). A number of other examples involving perceptual completion have been reviewed by Pessoa et al. (1998).

Work like that described above has been received with enthusiasm: researchers believe that the discovery of neural representations that correlate with perceptual experience brings us closer to understanding what gives rise to the perceptual experience. The underlying assumption is that if a set of neurons is found in the brain which correlates strongly with aware perceptual states, then, because these neurons are probably linked to the mechanisms that are generating awareness, we are likely to be able to explain perceptual awareness by appeal to this neural activity.

But this reasoning is unsound. Indeed, consider what would happen if we were to actually find a set of neurons that correlated *perfectly* with visual awareness. For the sake of illustration, suppose we were to discover that in the pineal gland of macaque monkeys there was a tiny projection room in which what is seen by the monkey was projected onto an internal screen whose activity correlated perfectly with the monkey's visual awareness. On reflection it is clear that such a discovery (which would surely be the Holy Grail of a neural correlate of consciousness seeker!) would not bring us any closer to understanding how monkeys see. For we would still lack an explanation of how the image in the pineal gland *generates* seeing; that is, how it enables or controls or modulates the forms of activity in which seeing consists. We would certainly be entitled, on the basis of the strong correlation between features of what is seen and features of what is projected onto the pineal projection screen, to assume that this neural activity played some role in vision. But nothing more could be said about such a discovery.

Why do some researchers believe that to understand the nature of consciousness or vision it is necessary to track down the neural representations that correlate with conscious experience? One possible explanation is that these researchers are (perhaps unwittingly) committed to the idea that the discovery of *perfect* correlation would give us reason to believe that we had discovered *the* neural activity sufficient to produce the experience (as suggested by Chalmers 1996a). Teller and Pugh (1983) call such a neural substrate of experience the bridge locus. In addition, thinkers may unwittingly subscribe to what Pessoa et al. (1998) have called *analytic isomorphism.* This is the view that for every experience there will be a neural substrate whose activity is sufficient to produce that experience (a bridge locus), and that there will be an isomorphism (though not necessarily spatial or topographic) between features of the experience and features of the bridge locus. It is the existence of such an *isomorphism* that works to justify the claim that the discovery of such a neural substrate would *explain* the occurrence of the percept.

We believe that one must reject the metaphysical dogma of analytic isomorphism. As argued by Pessoa et al., no neural state will be sufficient to produce experience. Just as mechanical activity in the engine of a car is not sufficient to guarantee driving activity (suppose the car is in a swamp, or suspended by a magnet), so neural activity alone is not sufficient to produce vision.

Note also that if this view is correct, then it is a mistake to expect to find neurons which *are* perfectly correlated with visual consciousness. Ultimately, visual consciousness is not a single thing, but rather a collection of task and environment-contingent capacities, each of which can be appropriately deployed when necessary. Furthermore, we expect that if neurophysiologists do find neurons that correlate strongly with awareness, then most likely this will only be for one or another set of conditions or tasks.

8.3. There is no need for "binding"

Neuroanatomists believe that the visual system is composed of numerous, more or less independent subsystems (or modules), which extract a variety of different attributes such as color, contrast, depth, orientation, and texture from the visual stimulus (e.g., De Yoe & van Essen 1988; Livingstone & Hubel 1988; Zeki 1993). The fact that these modules operate independently and are often localized in different cerebral regions, raises the question of how the separate streams of information ultimately come together to give us the unified perception of reality that we subjectively experience. One suggestion for solving this so-called "binding problem" was the idea of the "grandmother cell" in which single cells, or at least highly localized cerebral regions, combine information pertaining to specific percepts: for example, face-sensitive cells (Rolls 1992); place sensitive cells (O'Keefe et al. 1998); view sensitive cells (Rolls & O'Mara 1995). A more recent idea which does not require bringing signals into a single brain location has also received support from neurophysiological evidence (cf. Abeles & Prut 1996; Brecht et al. 1998; Castelo-Branco et al. 1998; Gray & Singer 1989; Llinas & Ribary 1993). According to this view, separate cortical areas which are concurrently analyzing the different aspects of a stimulus might oscillate in synchrony, and it might be this synchrony which provides the perceptual experience of unity.

There are two motivations in the reasoning which underlies these types of investigations: one concerns temporal unity, and the other concerns "conceptual" unity.

Certainly it is true that when we recognize an object, we have the impression that all its attributes are seen simultaneously at one "perceptual moment." This leads scientists to think that the objects' attributes must be bound together *synchronously* in the internal representation in order to provide the singleness of the perceptual moment. But this is a fallacy. Thinking that physical synchrony is necessary for having a synchronous experience is the same kind of fallacy as thinking that because things look like 3D models or picture postcards to us, there must be a topologically equivalent map in the brain. Underlying this fallacy is the implicit assumption that the synchrony or coherence of perception requires presenting information in a synchronous or coherent way to an internal homunculus. In fact, just as the perception of the 3D world does not require 3D maps in the brain, subjective simultaneity does not require simultaneity of brain events.[47] This point has been made by Dennett and Kinsbourne (1992; see also O'Regan 1992; Pessoa et al. 1998). What explains the temporal unity of experience is the fact that experience is a thing we are doing, and we are doing it *now.*

Coming now to the issue of "conceptual" coherence, a similar argument can be made: the fact that object attributes seem perceptually to be part of a single object does not require them to be "represented" in any unified kind of way, for example, at a single location in the brain, or by a single process. They *may* be so represented, but there is no *logical necessity* for this. Furthermore, if they are represented in a spatially or temporally localized way, *the fact that they are so represented cannot in itself* be what explains the spatial, temporal or "conceptual" phenomenology of perceptual coherence.[48] What explains the conceptual unity of experience is the fact that experience is a thing we are doing, and we are doing it with respect to a conceptually unified external object.

We noted above that were we to discover pictures in the brain that correlated with the experience of seeing, we would still not have moved much closer towards an explanation of seeing. But once we recognize this, then we further realize that there is no reason to suppose that to explain seeing we should seek for detailed internal pictures. There is no longer any rationale for supposing that there is a place in the brain where different streams of information are brought together and "unified" (whether conceptually or temporally). With the appreciation of this point we can dismiss the problem of binding as, in essence, a pseudoproblem.

8.4. A new way of thinking about the role of the brain in vision: A program for future research

We have already taken steps toward a positive characterization of the role of the brain in vision by claiming (as we have in sect. 8.1 above) that studies of the neural bases of vision must be framed by a consideration of the whole animal's broader behavioral and cognitive capacities. In this section we try to extend these remarks.

Consider the missile guidance system we discussed in section 2.4. Suppose that at the present moment the target airplane happens to have gone out of the field of view of the missile. No information, let us suppose, is coming into the missile's sights right now. Nevertheless, the missile guidance system has a certain potential: it "knows" that by making the appropriate change in its trajectory, it should be able to bring the missile back into view. Thus, even though at this particular moment the airplane is not visible and no visual information is coming in, it is still correct to say that the missile is currently tracking its target.

Exactly the same point, we argue, can be made about seeing and the sensorimotor contingencies governing seeing. When you make an eye saccade, the sensory stimulation provided by an object will change drastically due to very strong retinal smearing. At that very moment you do not receive sensory input from the object. But there is no more reason to think that this interruption in stimulation leads to an interruption in seeing, than there is to think that the missile is no longer tracking the plane when the plane happens to go out of the missile's sights.[49] The missile continues to track the plane, and the perceiver continues to see, because each is master of the relevant sensorimotor contingencies and each is exercising those capacities in an appropriate manner. Seeing an object consists precisely in the knowledge of the relevant sensorimotor contingencies – that is, in being able to exercise one's mastery of the fact that if, among other things, you make an eye movement, the stimulus will change in the particular way typical of what happens when you move your eyes. If the stimulation due to the object did not change in that way, then you would not be seeing the object – you might, for example, be hallucinating it.

These considerations call attention to the fact that interruptions and discontinuities in stimulation (owing to saccades, blinks, eye movements, chromatic aberrations, and other supposed defects of the visual apparatus) are in fact part of what seeing is. It is one's exercise of the mastery of just such regularities in sensorimotor contingencies in which seeing consists. What is striking for present purposes is that just as moments of stillness and inactivity may be essential to the performance of a dance, so moments of neural inactivity may be precisely what characterizes the exercise of sight. This is a fact that can only come into focus through a conception of vision as a mode of activity such as that developed by the sensorimotor contingency theory.

Considerations such as these show further, that although neural activity is necessary for vision, there need be no one-to-one mapping between seeing and occurrent neural states and processes. Vision requires all manner of neural events, but crucially, in our view, the experience of seeing itself cannot be equated with the simultaneous occurrence of any particular neural activity. This follows from the fact that, at any given moment, the brain may be inactive.

What then is the function of the brain in vision? Very generally speaking, it is to enable the knowledge and exercise of sensorimotor contingencies. Seeing, we argue, is constituted by the brain's present attunement to the changes that would occur as a consequence of an action on the part of the perceiver. Visual experience is just the exercise of the mastery of relevant sensorimotor contingencies. An example may help to make the point clearer. Your visual apprehension of the roundness of a plate consists in part in your knowledge that changes in your relation to the plate (movements relative to the plate) will induce changes in the plate's profile. That it looks round to you now, despite its elliptical profile, is constituted by your application, now, of skillful mastery of the appropriate rule of sensorimotor contingency. Other rules of sensorimotor contingency may be, as it were, more low level. As you move your eye across a straight line (as discussed in sect. 2.2), there is a characteristic pattern of transformation of the retinal stimulation. The brain is attuned to this pattern. One important function of the brain may thus consist in the testing of the appropriateness of the application of certain patterns of sensorimotor contingency.

An important advantage of this view is that it allows us to escape from the problem of having to explain how brain activity could give rise to experience. We escape from this problem because we propose that experience does *not* derive from brain activity. Experience is just the activity in which the exploring of the environment consists. The experience lies in the doing.

8.5. Toward a sensorimotor approach to visual neuroscience

A good deal of recent neuroscientific research shows that to understand the role the brain plays in supporting perceptual and motor capacities, it is necessary to keep clearly in view the broader context of the animal's skillful task-oriented activity. Specific neural states cannot be perfectly correlated with specific perceptual states. You cannot understand the contribution of neural activity if you restrict yourself to a brain's-eye view. This fits with our model of vision and visual consciousness. Seeing is not a simple occurrence; it is a rich, exploratory activity within a certain environment and with certain sensory apparatus, drawing on a number of heterogeneous capacities. Neural activity does not in itself produce experience. Neural activity contributes to experience only as enabling mastery and exercise of the laws of sensorimotor contingency.

An exhaustive survey of this neuroscientific research goes beyond the scope of the present discussion. Here we briefly indicate some examples.

8.5.1. Neural Plasticity and sensory substitution. A currently very active domain of investigation in neurophysiology concerns findings which show that cortical representations of visual or somatosensory information can change as a function of stimulation, use, or lesion. For example Pascual-Leone et al. (1993) show that the sensorimotor representation of the reading finger in the cortex of proficient Braille readers becomes greatly developed at the expense of the representations of other fingers (see also Sterr et al. 1998). Sadato et al. (1998) have suggested that in proficient Braille readers, tactile processing is "rerouted" to occipital visual cortex (see also Cohen et al. 1999). The cortical representation of owl monkeys' fingertips become enlarged when the monkeys engage in haptic exploration training (Jenkins et al. 1990a). Iriki et al. (1996) found that receptive fields of bimodal (somatosensory and visual) neurons in the caudal postcentral gyrus of macaque monkeys were altered during tool use "to include the entire length of the rake or to cover the expanded accessible space." Other examples include reorganization of cortical representations as a result of intracortical microstimulation, cortical lesions, digit amputation or fusion (cf.; Jenkins et al. 1990b; Merzenich et al. 1984; 1987; Wall et al. 1986), as well as the result of von Melchner et al. (2000) showing that auditory cortex of ferrets can be "rewired" to process visual information.

8.5.2. Attention and action. Rizzolatti and his colleagues have developed a "premotor theory of spatial attention" according to which, first, "conscious space perception results from the activity of several cortical and subcortical areas, each with its own neural space representation" (Rizzolatti et al. 1994, p. 232), and second, these "neural maps" directly function in the guidance of movement and action. There are not two systems, one for spatial attention and one for action. "The system that controls action is the same that controls what we call spatial attention" (p. 256). These claims dovetail with psychophysical, psychological, and neuroscientific evidence demonstrating linkages between perception and motor action. For example, Kustov and Robinson (1996) studied "superior colliculus in monkeys as they shifted their attention during different tasks, and found that each attentional shift is associated with eye-movement preparation" (p.74). Another line of evidence linking spatial attention and motor activity comes from studies of neglect in animals and humans with damage to cortical motor areas (Kinsbourne 1987; 1995; Rizzolatti et al. 1983). Neglect appears to be best understood as a difficulty in shifting attention to the affected part of the visual field. The fact that neglect should arise from damage to cortical areas serving motor activity further demonstrates the link between attention and motor activity.

8.5.3. Two visual systems: The what and the how. In the last few years, a very influential view of the structure of the visual brain has surfaced, according to which there are two streams of visual processing, a dorsal stream and a ventral stream. Opinions differ on the exact functions of the two systems, but Ungerleider and Mishkin (1992) distinguish between a dorsal "where" system devoted to localizing objects, and a ventral "what" system devoted to identifying them. A somewhat different classification has been proposed by Goodale and Milner (1992; cf. also Milner & Goodale 1995), who emphasize that the dorsal system is concerned with coordinating actions directed towards objects, whereas in the ventral system recognition and classification operations are performed which allow persons to memorize and reason about objects. Jeannerod (1997) refers to the dorsal stream as "pragmatic," in that it provides the ability to make the necessary transformations between visual input and motor output to locate an object with respect to the body, and to grasp and manipulate it, and calls the ventral stream the "semantic" system. Evidence for this latter interpretation of the two streams hypothesis comes from studies of the effects of lesions in humans (Milner & Goodale 1995). As Milner and Goodale point out, damage to the dorsal stream is associated with impairments of visuo-motor control such as optic ataxia (Harvey 1995) in the absence of impairments of the subject's ability to make verbal reports about the shape, features, and location of what is seen. Conversely, damage to the ventral stream produces visual agnosias (Benson & Greenberg 1969; Milner et al. 1991) without impairing visuo-motor functioning.

From the standpoint of the sensorimotor contingency view we propose here, the possibility of this kind of double dissociation is not surprising. In our view, seeing is an activity depending on a broad range of capacities, for example, capacities for bodily movement and guidance, on the one hand, and capacities for speech and rational thought, on the other. To the extent that these capacities are independent, it is not surprising that they can come apart in the manner described. It is not surprising, therefore, that the dorsal system can operate in relative isolation from the ventral system.

These points lead us to doubt, on certain interpretations at least, Milner and Goodale's claim that what the visual agnosia patient DF (who retains normal visuo-motor skill) lacks is *visual awareness* of what she sees. Milner and Goodale suggest that, like DF, normals carry out visually guided actions using information that is not present in awareness; and they say that only information in the ventral stream enters awareness. According to the view developed here (the sensorimotor contingency view), people are aware of what they see to the extent that they have control over that information for the purposes of guiding action and thought. Awareness is always, we have argued, a matter of degree. Even the distracted driver is somewhat aware of what he sees, to the extent that, if we were to ask him, he would tell us what he is looking at. The case of DF is thus a case of what would seem to be partial awareness. She is unable to describe what she sees, but she is otherwise able to use it for the purpose of guiding action.

This may seem like a purely verbal dispute, but there is an important point at stake here. What makes the information conscious or aware, in our view, cannot consist just in the activity or lack of activity in a certain brain region (e.g., the ventral stream). Consciousness or awareness is not a property that informational states of the brain can just come to have in that way. Rather, visual awareness is a fact at the level of the integrated behavior of the whole organism. The work of Milner and Goodale suggests that damage to the ventral stream disrupts non-visuo-motor aspects of seeing. This is an important finding. But it would be a mistake to infer from this that the ventral stream is therefore the place where visual awareness happens.

Apart from the above provisos, the "two visual systems" view fits well with the position we develop in this paper. First, as expected from the sensorimotor contingency based approach, at the neural level there is a tight connection between seeing and moving. Second, the two-systems approach provides evidence supporting a claim we have made at different stages in this paper, namely, that seeing does not depend on the existence of unified representations of what is seen. In the two-systems approach, for example, there is not one single representation of space in the brain.

In this connection, it is worth mentioning here that the "two visual systems" approach is also relevant to the scheme for classifying sensorimotor contingencies introduced in section 2.

Processing in the two streams will in general have to be done in different coordinate systems. In order to allow reaching for an object and manipulating it, the "where" system will have to make use of the position of the object relative to the observer's body. On the other hand, in the "what" system, recognition and classification of an object will require knowledge about the intrinsic shape of the object within an object-centered coordinate system, irrespective of the observer's position with respect to it.

This distinction between an observer-centered and an object-centered coordinate system is relevant to our classification of sensorimotor contingencies. In section 2 we emphasized that there are a subset of contingencies which are due to the particular spherical structure of the eyes, to the way they move, and due to the fact that sampling is being done by means of a two-dimensional perspective projection taken at a certain distance from the object, through optics and via a retinal mosaic that have very particular properties. These visual-apparatus-dependent rules are also constrained by the fact that the objects and the eyes are embedded in three-dimensional space (rather than, say, two-dimensional space): laws of variation like the inverse square law for the amount of light reaching the eye, the linear relation between distance and projected size, will be common to all objects which are sampled through the visual apparatus.

If we were to construct a neural network connected to an eye-like input device and to a muscle-like eye-mover, and have it learn the rules of dependency between its input and output, then the first rules which the neural network would adduce would be apparatus-based rules like the ones we have just described: these rules apply in all reasonably rich environments, irrespective of the objects contained in them. Furthermore, we see that the coordinate system useful to the neural network would be the observer-based coordinate system, since what has to be learnt by the network is those (in)variance laws of the space of sensorimotor contingencies which are occasioned by the observer's own movements. This learning would also provide the system with the notion of "self," since it will allow it to distinguish between parts of its environment which it can systematically control, and parts which it cannot. The notion of "object" would also be something that would emerge from such learning: an object is something which can be removed and put back into the visual scene. These facts about what might be called object-combinatorics are independent of the identity of the objects themselves, and are related simply to their intrinsic "objectness" and their embeddedness in three dimensional space. It is possible that the dorsal "where" system could have evolved to serve this function.

The second subset of sensorimotor contingencies we referred to in our classification was the subset which we described as "object-related." These contingencies are those that allow objects to be distinguished from one another, and to be recognized independently of their position and orientation. Clearly, a neural network which was trying to adduce laws of (in)variance from sensorimotor contingencies of this kind would have an advantage in coding information in object-centered, rather than observer centered coordinates. This is known to be the case for the ventral "what" system, which could have evolved for this purpose.

Note that our classification into apparatus-related and object-related sensorimotor contingencies is a somewhat artificial division. Many of the laws underlying sensorimotor contingencies could be said to be related both to the visual apparatus and to the nature of objects. For example, the fact that objects are embedded in three dimensional space has the consequence that they can show only one face to the eye, and that as they are turned or as the observer turns around them, different parts appear and disappear. These facts are both a consequence of the fact that the eye is operating from a distance and so capturing only a single point of view – an aspect of the apparatus, – and a consequence of the fact that objects have different sides – an aspect of the objects.

8.5.4. Downward causation. There is considerable evidence that when neural correlates of consciousness have been found, they are sensitive to mood, attentional set, and task. Varela and Thompson (e.g., Thompson & Varela 2001) have referred to the modulation of individual neurons by patterns of activity of populations of neurons and also by the attitude or set of the whole animal as "downward causation." So, for example, as stressed by Varela (1984) and Varela et al. (1991, p. 93; see also Pessoa et al. 1998, p. 736; Thompson 1995, p. 217; and Thompson & Varela 2001), responses in visual cells depend on behavioral factors, such as body tilt (Horn & Hill 1969), posture (Abeles & Prut 1996), and auditory stimulation (Fishman & Michael 1973; Morell 1972). Other studies show that attention and the relevance of a stimulus for the performance of a behavioral task can considerably modulate the responses of visual neurons (Chelazze et al. 1983; Haenny et al. 1988; Moran & Desimone 1985; Treue & Maunsell 1996). Leopold and Logothetis (1999) themselves write of binocular rivalry:

> We propose that the perceptual changes are the accidental manifestation of a general mechanism that mediates a number of apparently different behaviors, including exploratory eye movements and shifts of attention. We also propose that while the different perceptions of ambiguous stimuli ultimately depend on activity in the 'sensory' visual areas, this activity is continually steered and modified by central brain structures involved in planning and generating behavioral actions. (Leopold & Logothetis 1999, p. 254)

Leopold and Logothetis suggest that to understand perceptual reversals of the kind encountered when we view an ambiguous figure, or when we undergo binocular rivalry, it is necessary to consider not only neural activity in the visual cortex, but the animal's capacities for thought and action.

8.5.5. Upshot. Work in these and other areas provides evidence in favor of ways of understanding the role of the brain in vision and consciousness that are different from the ideas in the neural correlate of consciousness and binding problem research programs. Like work in the fields of dynamic systems theory (e.g., Kelso & Kay 1987) and embodied cognition both in robots and in animals or humans (Aloimonos 1992; Bajcsy 1988; Ballard 1991; Brooks 1991; Clancey 1997; Cotterill 1995; 1997), this research suggests the importance of accounts of the brain as an element in a system, and not, as it were, as the seat of vision and consciousness all by itself.

9. Conclusion

In this paper we have put forward a new framework for thinking about the nature of vision and visual consciousness. The solution to the puzzle of understanding how consciousness arises in the brain is to realize that consciousness does not in fact arise in the brain! Visual consciousness is not a special kind of brain state, or a special quality of informational states of the brain. It is something we do.[50]

From this point of view, understanding vision amounts to understanding the various facets of the things people do when they see. We suggest that the basic thing people do when they see is that they exercise mastery of the sensorimotor contingencies governing visual exploration. Thus, visual sensation and visual perception are different aspects of a person's skillful exploratory activity (that is, exploratory activity guided by practical knowledge of the effect movement will have on nervous influx). Visual awareness depends, further, on the person's integration of these patterns of skillful exercise into ongoing planning, reasoning, decision-making, and linguistic activities. As we have argued, these ingredients are sufficient to explain the otherwise elusive character of visual consciousness.

In addition, our proposal has the advantage of providing an account of what differentiates the sensory modalities. The problem is solved naturally, without appealing to the existence of sensory-modality-specific essences or mechanisms. Just as horse riding is different from motorcycling, so is seeing different from hearing. These differences can be explained without appeal to the essences of horseback riding and motorcycle riding, and without appeal to the specific nerve energies or pathways devoted to seeing and hearing. The difference between seeing and hearing is to be explained in terms of the different things that we do when we see and hear.

These are matters of philosophical significance, and we have sought, in developing our position, to make clear that in denying the need for *qualia,* we are not denying the existence of perceptual experience, or the possibility of phenomenological reflection on experience. Rather, we have proposed a new way of thinking about what goes on when we experience – which, as we have argued throughout, captures what we believe, as experiencers, about our experiential lives, but does so in a manner that does not give rise to the mystery of the explanatory gap.

These are matters of empirical significance. The sensorimotor approach to vision we have laid out here has provided the impetus for a series of surprising experiments on what has come to be known as change blindness. The robustness of these results in turn serves to vindicate the framework itself. In addition, we have tried to demonstrate that the sensorimotor view presented here allows for a unified approach to a variety of otherwise unconnected perceptual phenomena related to, for example, perceptual completion, inattentional blindness, perceptual stability despite observer eye-movement, prosthetic perception, color vision, inverting lens adaptation, the surgical restoration of sight in the congenitally blind, blindsight, the double dissociation of optic ataxia, and visual agnosia. We think it is striking evidence of the power of the position we develop here that it is able to account for such a broad range of perceptual phenomena.

Finally, if we are correct in our analysis, there is need for reassessment, on the part of neuroscientists, of the notion of neural correlate of consciousness. A way of thinking about the neural bases of perception and action is needed that does not rest on the false assumption that the brain is the seat of consciousness. We also believe that philosophers should consider the way in which empirical results in this area suggest the formulation of a new metaphysics of mind and body.

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NOTES

1. Cf. also Abeles & Prut (1996); Milner (1974); von der Malsburg (1983); Kahn et al. (1997); Rodriguez et al. (1999).

2. To suppose otherwise is to assume a particular account of psychoneural correspondence. But surely, how neural processes underwrite perceptual experiences is precisely what requires explanation. We can frame the problem in terms of Teller's notion of linking propositions (Teller 1983; 1984; Teller & Pugh 1983). Linking propositions specify the mappings between the forms of neural responses and the qualities of percepts.

3. See Gorea (1991) for a discussion of the relation of modern psychophysics to Müller's concept.

4. Koenderink (1984b) gave an example of how the shape of a tomato changes as you look at it from different angles. He called this the "aspect graph" or "visual potential" of the tomato. The concept of aspect graph has since then been extensively investigated in artificial vision.

5. This classical reasoning is an instance of what Pessoa et al. (1998) call "analytic isomorphism," that is, the view that at the neural substrate of an experience there must be an isomorophism between percept and substrate. Analytic isomorphism comes up again in our discussion of the neural basis of vision in section 8.

6. Koenderink (1984a) has a very perspicacious discussion of what it is to perceive, rather than simply to record information, where he makes this point.

7. Heil (1983), agreeing with Gibson and rejecting Müller's idea of physiological "channels" associated with different senses, also attempts a taxonomy of the different senses but does not suggest the idea that it could be the laws obeyed by the sensorimotor contingencies that are the essential fact that differentiates them.

8. Note that it could be claimed that Müller's idea of specific nerve quality could be salvaged by supposing that what differentiates the senses is different *calculations* that are done in the different pathways. This was suggested by Wittmann, Pöppel, and Schill, reviewers of the original version of this manuscript. In a way this is what is being proposed by the present approach, although we emphasize that the calculation itself is not enough. What is needed is for the structure of the input/output relationships to obey different laws.

9. Note that we have been careful not to say that vision or horseriding *provide* different experiences: the experience *is the fact of* engaging in the activities. The activities, we claim, are not *providing* an experience – though people often use the word provide in this way, we claim this is a figure of speech, and not indication of a true experience-generating mechanism. It is precisely this kind of misunderstanding which gives rise to the problem of the explanatory gap. Cf. section 6.3.

10. The possibility of machine awareness raises issues that go beyond the scope of the present discussion. We note here that because we admit that awareness comes in degrees, we are willing to say that to the extent that machines can plan and have rational behavior, precisely to that same extent are they also aware. But clearly, given the limitations of current machines' planning and rational behavior, and given the lesser diversity of their environmental interactions, the degree of awareness will be accordingly limited. If a chess-playing machine were able to purposefully lose a game so as to avoid upsetting a child, or if a medical diagnosis system were able to lie to a cancer patient about his condition, we would be more willing to accord higher degrees of awareness to it.

11. Merleau-Ponty (1968) has also compared vision to palpation.

12. We unfortunately became aware of Järvilehto's work too late to be able to give it full consideration.

13. Järvilehto (1999) has also made this point.

14. It is often assumed that transients must necessarily direct attention to a *location*. But presumably location is only one feature of visual stimuli, and in the brain, location may have a similar status to other features, like color, orientation, contrast, etc. Could it be that attention can be directed to aspects of a stimulus defined by such other features? For example, is it possible to direct attention to all the red items in a scene, or to scene region constituted by a 3D surface? Cf. Pylyshyn (1988) on this issue.

15. An excellent discussion of these topics can be found in Thomas (1999), who makes a convincing argument in favor of an "active perception" approach very similar to ours.

16. As observed by Stephen LaBerge (personal communication).

17. They observed no eye movement advantage but less than 50% correct performance in counting a grating pattern of identical vertical bars: it may be that the observers were using a strategy of estimating the number of bars by evaluating the number on the basis of the overall width of the pattern.

18. A portion of the existing data purportedly measuring the extraretinal signal under conditions of normal viewing can, to some degree, probably be explained by assuming that they are due to purely retinal effects (smear, retinal persistence, differences in spatio-temporal effects in central and peripheral vision; cf. O'Regan 1984).

19. It could be argued that people actually do have a detailed, picture-like internal representation of the outside world, but that it is destroyed at each saccade or on interruption by flicker and other transients. Alternately, as suggested by reviewers Wittmann, Schill, and Pöppel of our manuscript, it may be that we deceive ourselves as to the amount of detail we think we see in the representation. Such arguments are hard to square with data showing interaction of the change blindness effects with central/marginal interest manipulations, and with the data from the "mudsplash" experiments, among others. (cf. O'Regan et al. 1996; Rensink et al. 1997; 2000). Similar alternatives have also been discussed by Simons (2000b).

20. This view of the phenomenology of color perception is related to the idea of D'Zmura and Lennie (1986), who suggest that nonhomogeneity in retinal cone distributions could indeed be made use of by the visual system to determine surface reflectances. But in general, most current views of color perception assume that perceived color derives from applying some kind of color constancy calculation to the output of the long, medium, and short wavelength cone channels. The idea that perceived color is not the output of a constancy calculation, but rather is *constituted* by the applicability of laws of variation under eye movements, lighting conditions, and surface movements, appears not to have been seriously investigated up to now.

21. Broackes additionally notes: "And if it is puzzling how a dynamic property can make itself manifest in a static perception ('how can a disposition to present a variety of appearances be visible in a single appearance?'), then we already have, in familiar discussions of aspect-shift, the theoretical apparatus for a solution. It is because there is 'the echo of a thought in sight'." Broackes quotes Strawson (1974, pp. 52–53) who says: "To see [a newly presented object] as a dog, silent and stationary, is to see it as a possible mover and barker, even though you give yourself no actual images of it as moving and barking."

22. Broackes says that contrary to what he said in Broackes (1992), he is either protanomolous or protanope. (Broackes, personal communication.)

23. Cole (1991) has also invoked these studies in a functionalist defense against the inverted spectrum problem.

24. Curiously, many people wearing normal glasses seem to voluntarily peer over the rims of their glasses when they look at you, as though this procured some kind of advantage in seeing.

25. Dolezal stresses that the use of the terms upside down and right side up is confusing, and guards against saying that the world comes again to appear right side up. He says that in his experiment the final state of adaptation could be distinguished from the state before the experiment. Part of the reason for this could be that the duration of the adaptation was perforce limited, and because use of inverting goggles necessarily involves other constraints like the limited field of view and the weight of the apparatus. Howard and Templeton (1966) also stress the need to be wary of the terms upside down and right side up (see also Linden et al. 1999; Smith & Smith 1962).

26. Chapter 8 in Taylor's book contains a detailed, behaviorist theory of the effects of inversion of the visual world, referring to specific results of Stratton, Ewert, and Kohler. The outcome appears to be that the observed adaptation effects are to be expected, and that the nativist theory is "shattered" (p. 168).The chapter includes a mathematical appendix by Seymour Papert, who was the subject in Taylor's left-right inversion experiment.

27. The situation may be similar to what happens when you move to a new town, and attempt to orient yourself. It takes some time before local and global landmarks merge into a coherent representation of the town. Until that happens (and it may never do), you may make gross mistakes. For example, you may be perfectly able to orient yourself locally, but be unable to correctly indicate the direction of a well-known global landmark.

28. Bedford (1995) has a theory of perceptual learning which is related to the theory presented here.

29. Movies of the demonstrations can be found on the first author's web page at http://nivea.psycho.univ-paris5.fr. See also http://www.wjh.harvard.edu/~viscog/change/demolinks.shtml.

30. Movie demonstrations of some film-cut and other effects can be found on Simons' page at http://coglab.wjh.harvard.edu.

31. The following quote from Haines (1991) is an example: "Pilot F was a high-flight-time Captain who demonstrated exceptionally good performance both with and without HUD. The runway obstruction run was his seventh data run. He indicated his 'Decision (140 ft) . . to land (110 ft)', and proceeded to do so. The experimenter terminated the run at an altitude of 50 ft. The pilot was surprised. Captain: 'Didn't get to flare on this one.' First Officer: 'No you didn't . . . I was just looking up as it (the picture) disappeared, and I thought I saw something on the runway. Did you see anything?' Captain: 'No, I did not.' The experimenters suggested that an equipment failure was probably to blame. Both of these pilots saw the obstruction during the second exposure without HUD (13 runs and 21 runs later, respectively) and executed missed approaches. Later, when he was shown the videotape of this run, Pilot D said, 'If I didn't see it (the tape), I wouldn't believe it. I honestly didn't see anything on that runway'."

32. In Noë & O'Regan (2000) we discuss some philosophical aspects of the inattentional blindness work.

33. This demonstration may not work if the file is being viewed on the web or has been printed with the option of substitution of typography enabled. The point is that there are two ways of forming an "a"; one similar to the hand-written ɑ (a circle with a line next to it), and one similar to a typewriter a. If hand-written-like a's are mixed into a text, provided they have the same height and density as normal a's, this will generally not be noticed.

34. The word "of" is repeated. Repetitions of the word "the" can also be easily missed.

35. There are nine f's. Many people fail to count the f's in the three occurrences of the word "of."

36. In fact sensation itself is an abstraction, as already noted by James (1890/1950, vol. 2, p. 3).

37. Humphrey and Humphrey (1985) quote a blind man (D. Lepofsky, 1980) who has used a binaural sonic sensor mounted on eyeglasses for 5–10 hours a week for three years: "I am at the point that I react very naturally to its signals. I no longer have to think about what each signal could mean, rather, I react instinctively. I go around someone on the sidewalk without even realizing I've done it: that's how much a part of you it becomes."

38. Lenay et al. (1999) have discussed other reasons why TVSS systems have met with less enthusiasm on the part of blind people than might have been expected. He says: "Ce que cherche l'aveugle qui accepte de se plier à l'apprentissage du dispositif de couplage, c'est d'avantage la connaissance de ce dont les voyants lui parlent tant : les merveilles du monde visible. Ce qu'il espère, c'est la jouissance de cette dimension d'existence qui lui est inconnue. Or, ce n'est pas ce que donne ces dispositifs. Il y a de fait, de nombreuses différences entre le couplage artificiel et notre couplage visuel: il n'y a pas de couleur, peu de points, une caméra dont les mouvements sont difficiles et limités, ce qui donne une grande lenteur à la reconnaissance de la situation. Ce couplage sensori-moteur ressemble bien par certains aspects à celui de notre vision, mais l'expérience qu'il permet est toute différente, comme peuvent d'ailleurs bien le comprendre les voyants qui se prêtent à son apprentissage. Le dispositif de Bach-y-Rita ne réalise pas une substitution sensorielle, mais une addition, l'ouverture d'un nouvel espace de couplage de l'homme avec le monde."

39. Howells (1944) cited by Taylor (1962, p. 246) is an interesting example where association of a low and high pitched tone with red and green respectively, over 5,000 trials, gave rise to a perception of white being tinged with red and green when white was associated with the tones.

40. Bedford (1995) has a theory bringing together the McCollough effect and adaptation to prism displacement which is similar in concept to the present theory.

41. Of course, this is not to deny that vision may, under certain circumstances, involve feelings or sensations of a non-visual nature. So, for example, if you are trying to track the movement of an object without moving your head, you may feel a certain distinctive eye strain. If you witness an explosion, you may feel dazzled in a way which causes definite sensations in the eyes. If vision is, as we have argued, a mode of activity, then there may be all sorts of features that the activity consists of which in this way contribute to its "felt character." But crucially these are not *intrinsic* or *defining* properties of the experiencing, that is, they are not what philosophers think of as qualia. They are rather more or less accidental accompaniments of the activity of seeing on a particular occasion. Note, similar points can be made for the other sensory modalities. Bach-y-Rita (1996) has noted that perceptual experience may have a qualitative aspect in yet another sense. For those capable of vision, certain experiences may have a definite *affective* quality. This affective quality was reported to be absent in the quasi-visual experiences of patients using TVSS. So, for example, such patients lacked the familiar "feel" of emotion and familiarity when looking at a picture of a loved one, or the erotic charge that may be delivered by certain images in normal perceivers. Bach-y-Rita reports these differences as differences in qualia. This usage differs from that in the philosophical literature. In any event, we do not deny that experiences may be associated in this way with affect. In fact, the sensorimotor contingency view offers a basis from which to explain what may be going on here. One might speculate that what prevents tactile visual experiences from acquiring a full affective charge is the fact that tactile vision is not perfectly mastered, that is to say, it is not fully integrated into a sensorimotor skill set. A direct consequence of this strangeness is the fact that one's intimate dealings with one's loved ones have not been mediated by the exercise of the relevant sensorimotor skills.

42. Of course, when you drive a Porsche for the first time, you may at first lack *confident knowledge* of how the car will respond to your actions. Insofar as you are an experienced driver of cars, you will exercise confident mastery of how to drive. In so far as you are new to Porsches, you may be tentative and exploratory. You try to learn how the car performs. The distinctive feel of driving a Porsche for the first time thus can be understood to differ from the experience of the connoisseur.

43. One of the hallmarks of the tradition known as Phenomenology, associated with the work of Husserl and Merleau-Ponty, is a clear and rigorous conception of the methodology of first-person investigations of experience. Of great importance for appreciating this tradition, Husserl and Merleau-Ponty make contributions toward the development of a first-person study of consciousness which does *not* rely on the problematic conception of qualia criticized above. We are broadly sympathetic to work in this tradition. For recent contributions, see Varela and Shear (1999) and Petitot et al. (1999). Other traditions may also provide methods and concepts for first-person investigations of experience, for example, the mindfulness-awareness tradition in Tibetan Buddism. See Varela et al. (1991). Our use of the term "phenomenology" above, however, is not meant to refer specifically to these traditions but, rather, to the general problem to the solution of which these traditions make a contribution. Our central aim above is to make clear that we do not believe that there is any incompatibility between the sensorimotor contingency theory and a more full-blooded phenomenological project.

44. This has been shown for example by Chun and Nakayama (2000) in the context of experiments on change blindness (cf. also Chun & Jiang 1998).

45. An interesting question arises about the relation between what we think of as the animal's active engagement with the world and what, in the Phenomological Tradition, is known as the lived-body. This is a subject for further inquiry.

46. Research in the Phenomenological Movement associated with Husserl and Merleau-Ponty is concerned precisely with the development of just such first-person methods. It is ironic that Dennett criticizes Phenomenology from the heterophenomenological perspective (see, e.g., Dennett 1991, p. 44), since, as noticed by Thompson et al. (1999) and also Marbach (1994), Dennett's misdescriptions of experience often turn on misunderstandings that have been clearly understood as such within the Phenomenological Tradition.

47. In a criticism of Crick and Koch's arguments, Cogan (1995) also suggests that the notion of "perceptual moment" may not be useful. Dennett (1991) notes a similar point in his "multiple drafts" theory of consciousness.

48. A similar argument was made in section 5.5 with regard to the "filling in" of the blind spot: there may actually be what look like filling in processes in the brain, but these cannot be what provide us with the impression of the blind spot being filled in.

49. Of course, it is possible by attending to blinks (or eye movements), to become aware of the change in sensory input that they cause. But normally people do not attend to blinks or eye movements, and do not notice them. Certainly they do not attribute the sensory interruptions they cause, to changes in external objects.

50. Varela et al. (1991) and Thompson et al. (1992) also make this point. In their terminology, consciousness is something we enact.

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Editorial commentary

Let us simplify the problem of "consciousness" or "visual consciousness": Seeing is feeling. The difference between an optical transducer/effector that merely interacts with optical input, and a conscious system that sees, is that there is something it *feels like* for that conscious system to see, and that system feels that feeling. All talk about "internal representations" and internal or external difference registration or detection, and so on, is beside the point. The point is that what is seen is felt, not merely registered, processed, and acted upon. To explain consciousness in terms of sensorimotor action, one has to explain why and how any of that processing is *felt;* otherwise one is merely giving an optokinetic explanation of I/O (Input/Ouput) capacities (and of whether those capacities are actually or optimally generated by sensorimotor contingency processors, analog representations, symbolic representations, or other forms of internal structure/process), not of the fact that they are felt. Nor will it do to say "qualia are illusions." Qualia are feelings. Am I under the illusion that I am seeing (i.e., feeling) something right now? What is the truth then? That I am not feeling, but merely acting? No, I'm afraid Descartes had it right. Certain things are not open to doubt. They either need to be explained, or passed over in silence, in favor of the unfelt correlated functions that we *can* explain (Harnad 1995; 2000; 2001).

Visual conscious perception could be grounded in a nonconscious sensorimotor domain

Ulrich Ansorge, Ingrid Scharlau, Manfred Heumann, and Werner Klotz

Department of Psychology, Bielefeld University, Bielefeld, 33501, Germany.
{ulrich.ansorge, ingrid.scharlau, manfred.heumann, werner.klotz}@uni-bielefeld. de http://www.psychologie.uni-bielefeld.de/public/{uansorge/, scharlau/, mheumann/}

Abstract: Visual conscious perception could be grounded in a nonconscious sensorimotor domain. Although invisible, information can be processed up to the level of response activation. Moreover, these nonconscious processes are modified by actual intentions. This notion bridges a gap in the theoretical framework of O'Regan & Noë.

According to **O'Regan & Noë** (**O&N**), conscious perception depends on actually applied sensorimotor contingencies, and the authors provide a wealth of data that convincingly support this notion. Although the argument is not entirely new (e.g., Gurwitsch 1964; Straus 1963), it deserves repetition, because it is important, and seems to have been unacknowledged or forgotten by many. However, **O&N** do not detail which processes give rise to specific conscious content. Several alternatives are conceivable: Inadequate phenomenal content could be replaced by adequate content, less precise by more precise, or nonconscious data could give way to phenomenal content. Data from our laboratory suggest that the latter possibility may be a valid option.

Ruling out residual conscious perception. In reply to the repeated methodological critique of studies of nonconscious visual information processing (Dulany 1997; Eriksen 1960; Holender 1986; Reingold & Merikle 1988), Klotz and Neumann (1999) convincingly demonstrated that visual information, backward-masked and definitely not consciously perceived, was nonetheless processed. In that study, invisible primes led to an increase of reaction time (RT) to a visible target if they indicated alternative responses compared to the targets, and to faster responses if they indicated the same responses as the targets. Most noteworthy, Klotz and Neumann found no evidence for a residual conscious perception of the invisible primes; although forced-choice judgments, and confidence ratings to signal the presence of the primes were employed, judgments were made under a variety of different instructions (e.g., speeded vs. non-speeded), and transformed to the most sensitive index of residual perception (d'; Green & Swets 1966), and although feedback, training, and high monetary rewards for correct performance were provided.

Direct parameter specification. Some historical theories of nonconscious processing may have been far-fetched or difficult to test, but several recent conceptions are not characterized by these shortcomings (Bridgeman 1992; Milner & Goodale 1995; Neumann 1989; 1990). For example, according to Neumann's (1989; 1990) concept of direct parameter specification, visual information can be used to specify the final open parameter of an overt response without a conscious percept of the critical information, provided that action planning has been completed. Two predictions derived from this theory were successfully tested: a response activation by invisible information, and the dependence of the processing of the nonconsciously registered information on actual intentions of the agent. Both results also support the assumed role of sensorimotor processes for conscious perception as outlined above.

First, the activation of responses by invisible information was demonstrated by showing that invisible primes interfered more strongly with responses to visible targets if the primes indicated an alternative response than if they indicated no response (Ansorge & Neumann 2001; Ansorge et al. 1998; Jaskowski et al. 2002; Klotz & Neumann 1999; Klotz & Wolff 1995; Leuthold & Kopp 1998; Neumann & Klotz 1994). Moreover, response activation by invisible primes was also evident in the lateralized readiness potential (LRP) of the EEG, which reflects activity in motor areas of the human cortex (Dehaene et al. 1998; Eimer & Schlaghecken 1998; Leuthold & Kopp 1998; Neumann et al. 1998). Second, the processing of the invisible primes apparently depended on actual intentions of the agents. Participants had to know which specific information was mapped to which alternative response at least 250 msec prior to the invisible primes (Neumann & Klotz 1994, Experiment 4). Otherwise, the primes' impact was compromised, presumably because time was too short to transform the mapping rule into a corresponding intention. Likewise, if primes did not contain information appropriate to specify one of the required responses, they did not interfere at all (Ansorge & Neumann 2001, Experiment 3).

In sum, processing of nonconsciously registered information can indeed be sensorimotor (i.e., up to the level of response activation) and is determined by aspects of the actual situation (i.e., by the currently active intentions), supporting our notion that information might be applied in the course of mastering sensorimotor contingencies prior to the conscious perception of the same information. Besides, it seems that rather diverse visual features can be processed in the nonconscious sensorimotor domain. Evidence for response activation by invisible shape (Klotz & Wolff 1995), position (Neumann & Klotz 1994), color (Schmidt 2000), and even semantic information (Dehaene et al. 1998) has been obtained.

The functional value of processing nonconsciously registered visual information. Our proposal provides an answer to the question of what the functional value of processing nonconsciously registered visual information might be.

Of course, virtually everybody would agree that it takes time to consciously perceive, so that visual information remains nonconscious at least during an initial phase of information processing. A very important aspect of our proposal is that even motor processes involving the most peripheral effectors might be part of this initial phase. It is the organism that processes information into conscious content, not one of its (central) organs – its brain, or whatever subunit of it. Like data employed in processes of an organism's brain, those used in sensorimotor coordination could therefore in principle remain nonconscious; for example, if the processing sequence is interrupted prior to conscious perception. But, what is more, this notion suggests how specific information that is not consciously perceived might nonetheless routinely contribute to phenomenal aspects in a more unspecific way. For example, the felt veridicality of the content of conscious perception could be grounded in verifying visual information in a consciousness-independent domain of sensorimotor coordination.

In conclusion, in addition to its evident power in explaining aspects of phenomenal content, **O&N**'s theory provides a useful framework for integrating conscious and nonconscious functions.

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The role of the brain in perception

Paul Bach-y-Rita[a, b, c] and Steven J. Hasse[a]
[a]*Departments of Rehabilitation Medicine and* [b]*Biomedical Engineering, University of Wisconsin-Madison, Madison, WI 53706 USA;* [c]*Facultad de Medicina, Universidad Autónoma del Estado de Morelos, Cuernavaca, Mexico.* **pbachyri@facstaff.wisc.edu** **shaase@facstaff.wisc.edu**

Abstract: The recent interest of cognitive- and neuro-scientists in the topic of consciousness (and the dissatisfaction with the present state of knowledge) has revealed deep conceptual differences with Humanists, who have dealt with issues of consciousness for centuries. O'Regan & Noë have attempted (unsuccessfully) to bridge those differences.

Commenting on the chasm between scientific and philosophic analyses of human consciousness, Gardner (2001) stated, "For centuries humanists have cherished consciousness as their domain. . . For most of the last century, behavioral scientists eschewed that territory. But in recent years, cognitive scientists and neuroscientists have begun at least an assault on the fortress." In a review of a dialogue between a neuroscientist (Changeux) and a philosopher (Ricoeur), Gardner (2001) discussed their deep conceptual differences. He noted: "At one point, Ricoeur states 'I see with my eyes.' Changeux retorts, 'I would say that I need my eyes in order to see. . . one really ought to speak of his brain.' Ricoeur counters. . . 'I see with my eyes, because my eyes belong to my bodily experience, whereas my brain does not.'" This would appear to be consistent with **O'Regan & Noë**'s (**O&N**'s) view; however, it is challenging for neuroscientists to comment on a target paper that appears to see little role for the brain in vision, perception or consciousness, with statements such as "The solution to the puzzle of understanding how consciousness arises in the brain is to realize that consciousness does not in fact arise in the brain!" (target article, Conclusion).

There is reason for dissatisfaction with the present state of knowledge about brain mechanisms related to vision and consciousness, and many of us share it. Cartesian dualism and its "theater in the brain" (therefore also the notion of "pictures-in-the-head"), as well as the "grandmother cell," are outmoded. There are a number of approaches that explore possible mechanisms of information management, perception, and consciousness that provide insights, but perhaps not definitive explanations. But that is not sufficient to support the approach of **O&N**, who appear to consider that because other explanations are inadequate, theirs is proven. In fact, if one were to agree with their view that conscious visual experience results from "exercising mastery of the sensorimotor contingencies," and that "Visual awareness depends, further, on the person's integration of these patterns of skillful exercise into ongoing planning, reasoning, decision-making, and linguistic activities" (Conclusion), then one would also have to acknowledge that these processes are dependent on high-level brain events.

While it may one day be determined that a complete neural account of vision will still be unable to explain the subjective, personal quality of visual experiences (Dodwell 2000), a number of recent approaches seem to be heading in the right direction. For example, Harth (1993) favors a physicalist approach, by which he means "the working assumption that the broad field of Physics must ultimately account for most things we observe, including our own minds. This differs fundamentally from orthodox materialism because it leaves the door open to the unknown laws and relations of a yet to be explored territory." He explores the feedback loops within the central sensory paths, including perceptual levels higher than the visual cortex. Similarly, in arguing against strictly feed-forward theories of visual information processing (which "picture theory" seems to be based upon), Di Lollo et al. (2000) note that: "On this hypothesis, activity proceeds from primary cortex to other visual areas where input signals are convolved with stored information. The coded signals are then returned to lower centers for further processing." They, as well as Harth, emphasize the importance of reentrant signals in visual processing. A recent approach offered by Bachman (2001) can integrate the approach advocated by cognitive and ecological theorists in a way that is perhaps most consistent with **O&N** in that, "evolutionary regularities begin to control the active representational process" in addition to the importance of the organism-environment interaction in explaining perception. Bachman also details evidence of how percepts evolve very quickly over time, and carry with them traces of phylogenetically older representational content in their initial "stages." The very first sensory representations and responses were quite local to the membrane-environment interface, "but with further evolutionary development. . . representations evolve which, if activated and used, gradually take over the function of the site where sensitivity and perceptibility actually rest."

The authors are not alone in rejecting the notion that there are internal pictorial representations. Even in his earlier work, Kosslyn (1980) described mental image representations as "quasi-pictorial entities" as opposed to actual "pictures-in-the head." What does seem clear is that people can generate internal spatial-like representations and make functional use of them (e.g., navigating based on cognitive maps, recognizing meaningful patterns in stimulation based on learning, and even in developing scientific theory (Shepard 1978). Shepard (1978) has also argued that mental images are not "pictures-in-the-head." but rather are representations which to some degree match the relationships among real objects (i.e., second-order isomorphism). Our tactile vision substitution studies (Bach-y-Rita et al. 1969; Bach-y-Rita et al., in press) have emphasized that motor-sensory interaction is important for image acquisition and spatial localization. However, how those images are produced and stored, and how mental images in memory are accessed, remains unknown. Thus, the viewpoints of **O&N** are welcome in the quest for an understanding regarding the most complex processes that relate to perception and consciousness – provided the brain is not thrown out with the bath water!

Visual awareness relies on exogenous orienting of attention: Evidence from unilateral neglect

Paolo Bartolomeo[a] and Sylvie Chokron[b]
[a]*INSERM Unit 324, Centre Paul Broca, F-75014 Paris, France;* [b]*LPE-CNRS UMR 5105, UPMF, BP 47 38000 Grenoble, France.* **paolo@broca.inserm.fr**
http://paolo.broca.inserm.fr/ **chokron@upmf-grenoble.fr**
http://www.upmf-grenoble.fr/upmf/RECHERCHE/lpe/index.html

Abstract: Unilateral neglect stems from a relatively selective impairment of exogenous, or stimulus-related, orienting of attention. This neuropsychological evidence parallels "change blindness" experiments, in which normal individuals lack awareness of salient details in the visual scene as a consequence of their attention being exogenously attracted by a competing event, suggesting that visual consciousness requires the integrity of exogenous orienting of attention.

O'Regan & Noë (**O&N**) propose a new account of vision according to which seeing is a way of acting. In this approach, vision is a mode of exploration of the world that is mediated by knowledge of what the authors call sensorimotor contingencies. Thus, when we look at an object, the visual quality of its shape is the set of all potential distortions that this shape undergoes when it moves relative to us or when we move relative to it. Although this is an infinite set, the brain can abstract a series of laws from it and it is this set of laws which codes shape. The idea that the world constitutes an outside memory and that we only see what we are currently attending to, is consistent with the results of "change blindness" experiments reviewed by **O&N** in the target article. These experiments demonstrate that in many cases normal observers have great difficulty seeing changes, even though the changes are very large and occur in full view. This phenomenon, observed in normal healthy subjects, is a reminder of neglect symptoms often observed after a unilateral posterior brain damage. Patients suffering from left neglect after right brain damage fail to respond, attend to and explore left-sided stimuli.

We agree overall with the authors concerning the importance of sensorimotor contingencies of vision and find that many arguments in the target article are fascinating. Although the authors invoke some evidence from neuropsychological disorders of vision (unilateral neglect, visual agnosia) to support their hypothesis (sect. 8.5), we feel that the question of how their theory can account for these disorders should be further developed. For unilateral neglect, one could imagine an impairment of the sensorimotor contingencies concerning the left hemispace. This loss would explain the impossibility to process left-sided objects. However, it is now well known that there is no clear-cut division between a left neglected hemispace and a right unimpaired hemispace ; rather, neglect patients show a gradient of performance continuously ranging from left to right. Along those lines, left neglect could result from either a disruption of leftward shifts of spatial attention, or a facilitation for rightward attentional shifts, or both. In this framework, the sensorimotor account of vision could perhaps benefit from a more explicit reference to a directional component.[1] The positive effects of some rehabilitation techniques are consistent with the hypothesis of an impairment of the patients' knowledge of the sensorimotor contingencies associated with leftward orienting. Neglect patients can benefit from maneuvers combining sensory and motor demands, such as scanning the environment from left to right, moving actively the left limb while exploring the extrapersonal space, or actively adapting to optical prisms that displace rightwards the visual scene. These techniques might be understood as temporarily restoring patients' knowledge of sensorimotor contingencies associated with leftward orienting.

Considering the dichotomy between "exogenous" or stimulus-related and "endogenous" or strategy-driven orienting of attention, a large amount of evidence suggests that left neglect patients suffer from a relatively selective impairment of exogenous orienting with a relative sparing of endogenous processes. Interestingly, change blindness experiments also seem to imply exogenous orienting; a visual transient attracts attention at a specific location and entails a lack of awareness for concurrent events.

Regarding the need to postulate the existence of mental visual representations, it has been proposed that neglect could result from a lateralized amputation or a distortion of the mental representation of external space.

However, **O&N** deny that visual experience arises because an internal representation of the world is activated in some brain area. Visual experience would rather be a mode of activity involving practical knowledge about currently possible behaviors and associated consequences. Indeed, neglect patients do not necessarily show any representational disorder. To illustrate this point, we present the case of a 66-year-old male patient suffering from a left hemiparesis and left neglect signs two months after an ischemic lesion in the territory of the right anterior choroidal artery. We asked this patient to draw a butterfly from memory (Fig. 1), first with (upper panel), and then without (lower panel) visual guidance (while blindfolded), whereupon left neglect disappeared.

This observation confirms that left neglect may occur without any lateralized disorder of mental representation. In accordance with the hypothesis of an impaired exogenous orienting of attention in neglect, and similarly to the change blindness experiments,

Figure 1 (Bartolomeo & Chokron).

we propose that when drawing with visual guidance the patient's attention was attracted by the right-sided half just drawn, thus provoking the omission of left details. More generally, this confirms that a bias in exogenous orienting may entail a dramatic lack of awareness for visual events when a competing stimulus attracts the subject's attention.

For this reason, attentional orienting could be viewed as one of "the mechanisms of consciousness" (Posner 1994), thereby resolving the risk of tautology which, according to O'Regan & Noë, may affect attentional accounts of visual awareness.

NOTE

1. As a matter of fact, there is growing evidence that directional trends such as reading habits influence visual perception in normal individuals. Normal subjects demonstrate opposite biases as a function of their reading habits (from left to right or right to left like Hebrew or Arabic readers) in a variety of visuo-spatial task such as line bisection, line extension or aesthetic judgment.

Three experiments to test the sensorimotor theory of vision

Susan J. Blackmore

Department of Psychology, University of the West of England, St Matthias College, Bristol BS16 2JP, United Kingdom. **sjb_ac@hotmail.com**
http://www.uwe.ac.uk/fas/staff/sb/index.htm

Abstract: The sensorimotor theory of vision is the best attempt yet to explain visual consciousness without implying a Cartesian theatre. I suggest three experiments which might test the theory.

If we were thinking clearly about consciousness we should surely have crossed James's (1890) "fathomless abyss" by now, but we have not. I agree with Dennett (1991) that the root cause of our confusion is the seductive lure of the Cartesian theatre (CT) (that mythical place where consciousness happens; that imaginary container of the "contents of consciousness." Most existing theories – though their proponents deny it – entail some form of Cartesian theatre. Global workspace models do so, as do most current attempts to find the neural correlates of consciousness. Put at its simplest (and perhaps most extreme) we can say this. Ask the question "what is in my consciousness now?" (Or "what is in *x*'s consciousness at time *t*?"). If you believe there is an answer then you are imagining a Cartesian theatre.

O'Regan & Noë (**O&N**) provide the best attempt yet to escape from the clutches of the CT. Their theory is exactly the kind of bold departure that is needed. But is their theory right? And do they go far enough?

O&N suggest that "it is not possible to subject a general framework to direct verification." However, I think some of their central claims can be tested and I offer here three suggestions for doing so. These are not easy tests to perform but I hope they may reveal how different are the predictions of this theory compared with other, more traditional, theories of vision and visual awareness.

1. Scrambled vision. Traditional experiments using inverting goggles show that people gradually learn to see the world "the right way up," but during the learning phase they suffer two competing views, as described by **O&N**. We might imagine that in some way they gradually learn to invert their mental picture of the world. In the proposed experiment people would wear goggles that completely scrambled the visual input (this scrambling might also include blind spots, bars, or other gaps without affecting the argument). If O&N are correct, the new sensorimotor contingencies should be no more difficult to learn than with a simple inversion, but this time the subjects would effectively begin their learning blind. Their visual input would appear as noise and they would see nothing meaningful at all. As they learn the new contingencies by visual manipulation they would gradually come to see again. This new seeing would, if the theory is correct, be experienced as just like ordinary seeing. I would love to know what it is like to learn to see and would happily volunteer for such an experiment.

2. Manual vision. The feelings associated with facial vision in the blind might, in the spirit of **O&N**'s theory, occur because the sensorimotor contingencies of the face and ears are linked. That is, moving the ears necessitates moving the face. In this experiment auditory feedback is provided while subjects try to detect virtual objects in front of them by manually controlling the position of virtual ears. They could then move their faces independently of moving their "ears." In this case the theory predicts that they would feel things not on their faces but on their hands.

3. Blinded vision. Phenomena such as habituation and stabilised retinal images usually prompt only the conclusion that the visual system needs changing input to function. **O&N**, in contrast, propose that active manipulation of sensorimotor contingencies is required. This difference could be tested by yoking pairs of subjects together in the following way. 'A' subjects are able to move their eyes normally and explore a visual scene. 'B' subjects are given exactly the same changing visual input but their own eye movements are ineffective and uncorrelated with the input they receive. O&N's theory makes the strong prediction that 'A' subjects will see normally, but 'B' subjects – *while receiving identical visual input* – will be blind.

These tests, especially the last, might help find out whether **O&N**'s bold theory really holds or not. If it does they will have made a huge step towards eliminating the CT since in their theory seeing is a way of acting, not a way of building up unified representations of the world – or pictures in the CT. And incidentally (though they do not mention this), it may also explain the currently mysterious profusion of descending fibers in the visual system.

Nevertheless, their attempt is not, I suggest, completely consistent. For example, they claim (in sect. 2.6) that visual awareness requires not only mastery of the relevant sensorimotor contingencies but integration of this with thought and action guidance. There are possible counter-examples in both directions. First, fast actions that are controlled by the ventral stream are not normally reported as conscious (Milner & Goodale 1995) yet they should surely count as "action-guidance." This step is particularly odd since they helpfully point out problems with Milner and Goodale's analysis in section 8.5.3. Second, experience in meditation suggests that it is possible to stop all thought, planning, and overt action (if not sensorimotor manipulation) without losing vision.

Finally, a few subtle hints of the CT remain – showing just how hard it is to escape altogether. Such phrases as "features of the car enter consciousness" or "are available in consciousness" (sect. 6.2) imply a CT, as do the claims that some sensorimotor contingencies are "accessible to awareness," or are "brought into consciousness" (sect. 6.6). And there seems to be some confusion in the way they compare their views with Dennett's. While claiming that "qualia are an illusion" (sect. 6.3) and "the conception of phenomenal consciousness itself must be. . . rejected" (sect. 6.9), they nonetheless take Dennett to task for being "insufficiently attentive to the actual phenomenology of experience" (sect. 7.3). Yet, as Dennett famously says: "the actual phenomenology? There is no such thing" (Dennett 1991, p. 365).

Building a theory that does justice to the reality of consciousness without invoking a CT is extremely hard. I think **O&N**, in spite of these small problems, have come closer than anyone else. Their theory is bold, testable, and a rare step in the right direction.

Behaviorism revisited

Ned Block

Departments of Philosophy and Psychology, New York University, New York, NY 10003. **ned.block@nyu.edu**
www.nyu.edu/gsas/dept/philo/faculty/block/

Abstract: Behaviorism is a dead doctrine that was abandoned for good reason. A major strand of O'Regan & Noë's view turns out to be a type of behaviorism, though of a non-standard sort. However, their view succumbs to some of the usual criticisms of behaviorism.

O'Regan & Noë (**O&N**) declare that the qualitative character of experience is constituted by the nature of the sensorimotor contingencies at play when we perceive. Sensorimotor contingencies are a highly restricted set of input-output relations. The restriction excludes contingencies that don't essentially involve perceptual systems. Of course, if the "sensory" in "sensorimotor" were to be understood *mentalistically,* the thesis would not be of much interest, so I assume that these contingencies are to be understood non-mentalistically. Contrary to their view, experience is a matter of what mediates between input and output, not input-output relations all by themselves. However, instead of mounting a head-on collision with their theory, I think it will be more useful to consider a *consequence* of their view that admits of obvious counterexamples. The consequence consists of two claims: (1) any two systems that share that highly restricted set of input-output relations are therefore experientially the same; and (2) conversely, any two systems that share experience must share these sensorimotor contingencies. Once stated thus, the view is so clearly wrong that my ascription of it to the authors might be challenged. Yet, it is at least a consequence of a major strand within O&N's theory. Perhaps this will be an opportunity for them to disassociate themselves from it. I will limit myself to claim (1).

There are some unfortunate people whose visual apparatus has been severely damaged to the point where they can distinguish only a few shades of light and dark. You can simulate this "legally blind" state at home, though imperfectly, by cutting a ping-pong ball in half and placing one half over each eye. In addition, many people are paralyzed to the point where they can control only a very limited set of behaviors, for example, eye-blinks. For someone who has both problems, visual sensorimotor contingencies are drastically reduced. In fact, it would seem that they are so reduced that they could be written down and programmed into an ordinary laptop computer of the sort we find in many briefcases. If this were done, **O&N**'s thesis would commit them to the claim that the laptop has experiences like those of the legally blind paralytic I mentioned. (This form of argument derives from my reply to Dennett in Block 1995a, p. 273, and has been subsequently used by Siewart 1998.)

What would those experiences of the laptop have to be like? If you put the ping-pong balls on your eyes you can get some insight into the matter. My judgement is that such experiences are no less vivid than ordinary experience, although of course greatly reduced in informational content. Perhaps **O&N** will say that the paralysis dims the experience to the point where it is not so implausible that the laptop has such an experience. However, people who are temporarily completely paralyzed often report normal experience during the paralyzed period. In any case, can there be any doubt that such people do have *some* experience, even visual experience, and that the laptop has *no* experience at all? I would say the same for people who are *born* with severe limits to their visual apparatus but report visual experience with low informational content. There is every reason to think that these people have some visual experience and that the corresponding laptop has none.

Behaviorism in one form is the view that two systems are mentally the same just in case they are the same in input-output capacities and dispositions. There are standard refutations of behaviorism. (See, e.g., Block 1995c, pp. 377–384; or Braddon-Mitchell & Jackson 1996, pp. 29–40 and 111–121.) But what really killed behaviorism was the rise of the computer model of cognition. If cognitive states are computational states of certain sorts, behaviorism runs into the problem that quite different computational states of the relevant sort can be input-output equivalent. For example, consider two input-output equivalent computers that solve arithmetic problems framed in decimal notation. One computer does the computation in decimal whereas the other translates into binary, does the computation in binary, and then translates back into decimal. Delays are added to get the two computations to have the same temporal properties. Behaviorism doesn't fit with the computational picture of cognition; that's why it died.

O&N's view, in my interpretation, is a form of behaviorism. It isn't the general behaviorism that I just described because it is about sensory experience, not about cognition or mentality in general. And so it might be thought to escape the problem just mentioned. Since it is not about cognition, O&N don't have to worry about two different cognitive states being input-output equivalent or two identical cognitive states implemented in systems with different input-output relations. But their view is doomed by a similar problem nonetheless: the same input-output relations can be mediated either by genuine experience or by simple computations that involve no experience. Genuine experience need not have a complex computational role, and that less complex experience surely can be simulated in input-output terms by a system that has no experience. It should be equally obvious that the same experience could play different input-output roles in different systems.

Experience, attention, and mental representation

Justin Broackes

Department of Philosophy, Brown University, Providence, RI 02912.
Justin_Broackes@brown.edu

Abstract: O'Regan & Noë make plausible that perception involves mastery of sensory-motor dependencies. Their rejection of qualia, however, is less persuasive; as is their view that we see only what we are attending to. At times they seem to oppose "internal representation" in general; I argue that they should in fact only be rejecting crude conceptions of brain picturing.

This fascinating article makes very plausible the idea that perception involves mastery of sensory-motor dependencies. (I prefer "dependencies" to the authors' term "contingencies," which has perhaps unfortunate connotations of *non-necessity.* The real issue, of course, is how sensation varies with relative position of perceiver and perceived.) The authors also want to go further, however, and use the conception of sensory-motor dependency to attack the idea that perception involves an internal representation of the world. On that I have some doubts.

***1. Experiences as ways of acting*.** **O'Regan & Noë** (**O&N**) have a direct argument that the very idea of qualia involves what Ryle (e.g., in Ch. 1 of 1949/1990) called a category mistake.

> Qualia are meant to be properties of experiential states or events. But experiences. . . are not states. They are ways of acting. They are things we do. There is no introspectibly available property determining the character of one's experiential states, for there are no such states. Hence, there are, in this sense at least, no (visual) qualia. (Target article, sect. 6.3)

There is much here that goes to the heart of the authors' views. But I suspect the argument is too quick – and not quite as grammatically careful as Ryle himself would have wanted. There is much to be said against the idea that experiences are solely passive. (Think of 20 years' experience as the head of a secondary school, or the experience of swimming 10 miles in the rain.) But I doubt whether experiences are simply "things we do." As a first approximation, I'd suggest: the central cases of experience are neither active or passive alone. Rather, experience is what we have when we push against the world and the world pushes back. (Plato, interestingly, has a physical theory of vision which makes it literally a case of pressure and counter-pressure; see *Timaeus,* 45c.) The experience of swimming in the rain is something we get while performing that act. The swimming is something we do, the experience is not.

If that is true, then we can't immediately conclude that experiences are never states. It may sometimes be the case that when I act in a certain way, the world puts me into a certain state (e.g., a state of embarrassment, or of irritation). And if standing for minutes in front of a color field painting of Ellsworth Kelly's puts me into a particular perceptual state and keeps me in it, then the authors can hardly dismiss the qualia-lovers simply for talking of properties distinctive of that perceptual state. Other arguments may do the job – there may be much wrong with the particular qualities the qualia-lovers invoke; but the present argument seems too quick.

2. Attention and the field of view. It seems attractive to say that vision typically involves the experience of a whole range of things in front of the perceiver, only some of which at any one time are the object of attention. One possible development of that view would claim that vision involves the formation of an internal image, and the thinker's attention passes from certain things represented in parts of that image to other things represented in other parts of it. In their concern to reject the latter idea, **O&N** seem in danger of rejecting the first idea – which is really, I think, too important to be thrown away.

As you explore the scene in front of you, "each thing you ask yourself about *springs into awareness*" (target article, sect. 4.1, my emphasis). Before you ask about a particular feature (or direct your attention it), the information about it is "out there" and obtainable "by making the appropriate eye movement or attention shift," but, the authors insist, the information is at the earlier time "not currently available." An image of the detail in question may be "impinging on the retina," but still the item is "not actually being seen." **O&N** are right to remind us that when I turn my eye to the paper on the left of my desk, I start receiving information that I didn't have before: it is not true that I previously had an image of *the words* on that paper, and have simply come now to attend to that image. But they evidently want to go further, and deny that I was even aware of *the paper* before I was actually attending to it. We are under "the impression of seeing everything," but "only a small fragment of the world is actually being seen" (sect. 4.2). And the source of the mistake is that we confuse *being able to see x* with *actually seeing x* (sect. 4.6). When we have "continuous access to environmental detail," we all too readily suppose we have "continuous representation of that detail" (sect. 6.8).

In **O&N**'s view, we never see anything that we're not currently attending to. Since presumably we only attend to a few things at a time, it is as though we see through a narrow tube of attentional consciousness, never perceiving more than is currently in the attentional field. And if my attention is newly drawn to something, it can only be to something I am not already seeing. This is extremely implausible: surely while looking at and thinking of the books in front of me, I can also be aware of the paper off to the left. If someone moves the paper, I can easily be aware of this (even while keeping my eyes on the books. I am not merely *capable* of getting information about the paper, I am already doing so – though of course in less detail than about the things I'm looking at directly. The authors claim that before I actually attend to the object, information is "out there" but "cannot at this moment be used to control judgments and utterances" (sect. 4.1, para. 5); but that does not seems true of this kind of case. I can surely comment on gross features like the approximate size and orientation of the paper, and perhaps its color. If the authors insist that one simply cannot make a judgment about something without at that moment "attending to" it (just by virtue of *thinking* of it), then that again seems incorrect. Suppose that at time *t1* I look at my books, and am rather indistinctly aware of the paper off to the left; then I close my eyes and make a judgment at time *t2* about the color of the paper I saw shortly before. Indeed at *t2* I will be "attending" to the paper, but that hardly implies that at *t1* I was doing so already.

Thus, in my opinion, **O&N** are too quick to dismiss the idea of simultaneous visual representation of things, only some of which are attended to. It is true that we should not mistake mere availability of information for its actual supply; but we must also avoid the converse mistake. In fact what we need is to allow that, just as information from the things we see may vary greatly in degree of detail, so also visual experience will vary greatly in degree of detail (whether or not that experience is ultimately to be described in terms of pictorial representation.

3. Representation and interpretation. **O&N** offer several examples to confirm their idea that we often look at something without seeing it. The intention, I think, is to discredit representationalist views that would be forced to say that an item was "seen" simply because it was within the field of view. But I suspect the authors are too quick here. If a person counts the wrong number of f's in a sentence (like the example given in sect. 5.12), this may be because they have failed to see all of the f's; but it may also be that they saw them, but somehow treated some as "not counting" (i.e., perhaps, as not important enough to be counted). Writing the sentence out accurately could be a sign that the letters had been seen, yet might still be followed by failure in the counting task. In general, anyone who believes in representations (whether "in the mind" or "in the brain") will surely give a role not only to visual representation but also to (various forms of) something like inference and conceptual interpretation. And the latter seems too quickly forgotten by the authors. Take the case of change blindness (sect. 5.10). Under particular circumstances, a person may be unaware of a change, even quite a large one, in the scene before her. But is this definitely a case where the person does not "see" something in the visual field?

We need to distinguish between seeing *the change* and seeing *the objects* in view before and after the change. It may be that the person first sees the car and later sees the wall (now visible behind); but she doesn't realize what change has occurred. We are in no position to conclude that there are no mental representations here; the problem may simply indicate weaknesses in the operations or inferences the perceiver is trying to apply to (or with) such representations. This needn't be terribly surprising: a person may minutely examine two variant drawings on the back of a cereal packet for discrepancies, and still miss them, though there is no doubt that he has seen the car in the one picture, and the wall in the other. Searching for words in a 4 by 4 matrix of letters, I may find NOSE and miss STEP, though there's no doubt I have seen all the letters, and indeed the whole matrix. The problems may lie less with perception than with further mental operations.

4. Brain representations. The authors give, I think, very good reasons to be suspicious of the idea that there are brain representations that straightforwardly mimic the features found in our own perceptual experience. Their strongest argument is a functional one: there are, for example (sect. 8.5), two sets of perceptual abilities (supported by dorsal and ventral pathways – and each can apparently be disrupted while the other is left intact. Both are essential to vision, so we shouldn't expect vision to involve just a single unified representation. A similar lesson can be derived from the case (in sect. 5.9) where a person with inverting spectacles adapts in some respects but not in others: the world, for example, seems the "right way up" in general but license plates still look reversed. Here again, it seems there is more modularity and disunity than one would expect if dealing with a single brain representation.

O&N are arguing that functional disunity implies neural disunity. But if that argument is valid, then there is a case also for a converse argument, that functional similarity may derive from neural similarity. Where, for example, we find Kanisza triangles with illusory contours leading to the same kinds of behavior (under certain circumstances) as other triangles with real contours (cf. sect. 5.5), then the similarity in behavior (under those circumstances) could be very genuinely (if partially) explained if we found a place in the brain where something similar was going on in the two cases.

Perhaps the lesson is not that there are no such things as brain representations but that the representations are more distributed, fragmented, and multi-level than we thought, and they involve a variety of kinds of representation that show up in surprisingly complex ways in our capacities to get around in the world. Sometimes **O&N** seem to be dismissing only the crude conceptions of brain representations with "the metric properties of a picture" (sect. 5.5); at other times they seem to be dismissing "internal representation" in general (e.g., sect. 4.1). I suspect that the fascinating discussions of the present paper fail to give justification for the latter claim; I wonder if the authors might after all be satisfied with merely the former.

Sensorimotor chauvinism?

Andy Clark and Josefa Toribio

Cognitive and Computing Sciences, University of Sussex, Brighton, United Kingdom. **andycl@cogs.susx.ac.uk** **pepat@cogs.susx.ac.uk**

Abstract: While applauding the bulk of the account on offer, we question one apparent implication, namely, that every difference in sensorimotor contingencies corresponds to a difference in conscious visual experience.

O'Regan & Noë (**O&N**)present a wonderfully detailed and comprehensive defense of a position whose broad outline we absolutely and unreservedly endorse. They are right, it seems to us, to stress the intimacy of conscious content and embodied action, and to counter the idea of a Grand Illusion with the image of an agent genuinely in touch, via active exploration, with the rich and varied visual scene. This is an enormously impressive achievement, and we hope that the comments that follow will be taken in a spirit of constructive questioning. Overall, we have two main reservations.

The first, which we are sure others will pursue in more detail, concerns the claim to have dissolved or side-stepped the "hard problem" of visual qualia. Even if the contents of our conscious visual experiences reflect ways of acting in the world, the hard problem surely remains. A good ping-pong playing robot, which uses visual input, learns about its own sensorimotor contingencies, and puts this knowledge to use in the service of simple goals (e.g., to win, but not by too many points) would meet all the constraints laid out. Yet it seems implausible to depict such a robot (and they do exist – see, e.g., Andersson 1988) as enjoying even some kind of modest visual experience. Surely someone could accept all that **O&N** offer, but treat it simply as an account of how certain visual experiences get their contents, rather than as a dissolution of the so-called hard problem of visual qualia.

But more important, to our mind, is a reservation concerning the account even as a story about the determination of experiential content. The worry is that by pitching the relevant sensorimotor contingencies (SMCs) at quite a low level (they concern, after all, such things as the precise way the retinal image shifts and distorts as we move our eyes, etc.), the authors invite a kind of sensorimotor chauvinism. By this we mean that they invite the conclusion that every small difference in the low-level details of sensing and acting will make a difference to the conscious visual experience. Thus, for instance, imagine a being whose eyes saccade fractionally faster than our own. Some of the "apparatus-related" SMCs will then vary. But will the conscious experience itself vary? (It may come more quickly (but that is not the point. The question is: will it seem any different to the perceiver?)

We are not sure how such a question is to be resolved one way or the other. But there seems no a priori reason to believe that every difference in SMCs will make a difference to the experienced content, even if the SMCs (some of them, at some level) are indeed active in determining the content (compare, e.g., work on discriminable vs. non-discriminable differences in color).

Moreover, though we cannot defend this view in detail here (see Clark, forthcoming), there is some evidence to suggest that conscious visual experience is rather deeply tied up with the uptake of information in a form geared not to fine-tuned sensorimotor control but to memory, thought, reason, and planning (think of a somewhat weakened version of the dual visual systems hypothesis defended by Milner & Goodale 1995, and indeed mentioned by **O&N**). To whatever extent this is the case, it may be that the need to put the SMCs to use in the service of planning, reason and intentional action (a need properly stressed by the authors) serves as a kind of filter on the type and level of the SMCs especially relevant to conscious visual experience. Thus, we suspect that the important links between action and conscious visual content are mediated (for more on this, see Prinz 2000) by systems geared towards memory, planning, and reason.

The challenge, then, is for the authors to either refute the charge of sensorimotor chauvinism, or to show convincingly that every difference in SMC (both apparatus-related and object-related) yields a difference in visual experience.

Whither visual representations? Whither qualia?

Jonathan Cohen

Department of Philosophy, University of California San Diego, La Jolla, CA 92093-0119. **joncohen@aardvark.ucsd.edu**
http://aardvark.ucsd.edu/~joncohen/

Abstract: This commentary makes two rejoinders to O'Regan & Noë. It clarifies the status of visual representations in their account, and argues that their explanation of the (according to them, illusory) appeal of qualia is unsatisfying.

Whither visual representations? **O'Regan & Noë** (**O&N**) argue against conceiving of vision in terms of pictorial internal representations. They urge that "there is no '*re*'-presentation of the world inside the brain: the only pictorial or 3D version required is the real outside version" (target article, sect. 4.1). While their arguments against the existence of *pictorial* representations in the brain are persuasive, they are unsuccessful in showing that there are no internal visual representations.[1]

There are a number of traditional, if quotidian, reasons for positing internal, visual representations, and **O&N** say nothing that would undermine these. For example, you can remember the color of the coffee cup you used yesterday morning, even though it is now hidden in a cabinet (because the cup is hidden, your ability can't be explained by the "outside memory" of O&N's section 4). Although the details might vary, the standard explanation of this ability seems to require appeal to a persisting mental state that is (i) selectively sensitive to the coffee cup and its properties (e.g., its color), (ii) causally efficacious with respect to later processing, and (iii) generated in part by past visual interaction with the cup. Such a state is traditionally counted a representation because of feature (1) – it represents the coffee cup. It is traditionally counted as internal/mental because of feature (2) – it can be recalled and manipulated by later mental processes, and can survive radical alteration or even destruction of its object (the cup). And it is traditionally counted visual because of feature (3) – it is generated and maintained by the visual system.[2]

There are many other standard motivations for visual representations, most of which take the form of phenomena for which explanations are possible if there are visual representations, but not possible otherwise. To take a few examples almost at random, it is hard to explain perceptual priming, perceptual learning, or the dependence of recall time for visually presented items on their number, without supposing that the visual system forms representations of the world, and that these representations are operated on by mental processes with certain properties (e.g., effects on recall, chronometric properties). Significantly, there is no reason to suppose that the visual representations required by these explanations must be pictorial, that they are retinal projections, or that they otherwise exemplify geometric properties. On the contrary, accepting the standard explanations commits one only to the existence of internal, causally efficacious states that represent the world and are generated by the visual system.

I see no reason why **O&N** should deny the existence or significance of such states; consequently, I see no reason for them to deny the existence or significance of internal visual representations.

Whither qualia? Although **O&N**'s position on the nature of qualia amounts to a familiar brand of eliminativism, they supplement this position with a novel proposal about the source of the widespread belief in qualia (sect. 6.4).[3] O&N propose that subjects' belief in qualia has two main sources. First, subjects "overlook the complexity and heterogeneity of experience and this makes it seem as if in experience there are *unified* sensation-like occurrences." Second, the continuous availability of features of the visual scene to our attention gives subjects the false impression that they "continuously represent those features in consciousness."

Unfortunately, I don't see how these points explain subjects' belief in qualia. Grant that subjects make the errors **O&N** attribute to them; if these errors explain the illusion of qualia, then removing them should make that illusion disappear. Suppose, then, that subjects came to appreciate the complexity underlying visual experience (they learn about inhomogeneities in retinal photoreceptor densities, eye movements, color constancy mechanisms, and so on. I don't see how knowing about the complex structure of events that causally sustain our visual experiences would impugn subjects' belief that experiences have a certain qualitative character: belief in qualia seems to derive from subjects' phenomenological impressions about their own experiences, not from naïve speculation about the simplicity of visual mechanisms. Now consider the other purported source of the illusion – subjects' erroneous impression that they continuously and consciously represent visual features that are in fact unrepresented. Again, grant that subjects hold this erroneous belief. Why should this make them susceptible to a belief in qualia? Once again, correcting this erroneous belief seems not to affect a subject's belief in qualia: even a subject convinced she did not maintain continuous conscious representations of features in the visual scene might hold that her experience of looking at the scene has a qualitative character.[4]

Because a subject could believe in qualia without holding either of the two other beliefs **O&N** mention, it is hard to see these beliefs as the sources of the widespread appeal of qualia. If qualia are an illusion, this illusion must have its source elsewhere.

NOTES

1. I am unsure whether O'Regan & Noë mean to show this, or whether they intend to show only that, if there are such representations, they cannot be pictorial. Unfortunately, many of the formulations in the text are ambiguous on this point.

2. It is *not* counted visual because it can be seen, or because it exemplifies geometric or color properties.

3. O'Regan & Noë also argue that belief in qualia is *not* widespread because naive subjects don't understand the question "what is it like to look at the piece?" as a request for elucidation of the qualitative aspects of their experiences (sect. 6.5). I find this response unconvincing: surely the supposition that subjects have phenomenal access to qualia is compatible with their understanding the above question as not soliciting commentary about qualia. Putting this aside, it seems strange that O'Regan & Noë argue in section 6.5 that the illusion is *not* widespread among ordinary subjects when they attempt to explain its source in ordinary subjects in section 6.4: if the illusion is not widespread, there should be nothing to explain.

4. So it seems to me. Presumably these issues are empirically testable.

Trans-saccadic representation makes your Porsche go places

Peter De Graef, Karl Verfaillie, Filip Germeys, Veerle Gysen, and Caroline Van Eccelpoel

Laboratory of Experimental Psychology, University of Leuven, Leuven, B-3000, Belgium. **{Filip.Germeys, Veerle.Gysen, Caroline.Van Eccelpoel}@psy.kuleuven.ac.be**
http://www.psy.kuleuven.ac.be/labexppsy/top/{peterweb, karlweb, filipweb, veerleweb, carolineweb

Abstract: To eliminate the leap of faith required to explain how visual consciousness arises from visual representation, O'Regan & Noë focus on the sensorimotor interaction with the outside world and ban internal representations from their account of vision. We argue that evidence for trans-saccadic representations necessitates a central position for an internal, online stimulus rendition in any adequate theory of vision.

What is visual experience and where does it occur? In the homunculus who is sitting in a mental projection room, watching an internal representation of the outside world? Few modern day vision scientists will defend this caricature of visual perception. However, **O'Regan & Noë** (**O&N**) convincingly argue that the unattractive notion of an internal, interpretative agent is difficult to escape as long as one assumes that visual experience arises from the activation of internal representations or their neural substrates. By equating visual experience to the act of exploring the visual world, the sensorimotor account eliminates the gap between visual representation and consciousness. However, by equating vision to the exploration of our surroundings in search of confirmation of sensorimotor hypotheses, we feel that a new enigma is created. As we argue below, the visual system does maintain a representation of the visual environment. The question then becomes why this representation exists if the outside world is always there to be explored?

Although **O&N** state (sect. 4.1) that there is no "re"-presentation of the world inside the brain, we assume this claim only pertains to one particular type of representation. O&N do not seem to question the existence of feature representations (laws of sensorimotor contingency, sect. 2.2), spatial representations (sect. 8.5), and a lexicon of stored object and scene representations (webs of contingencies, sect. 3.3). The one representation which O&N do target is a detailed and continuously updated rendition of the visual environment, which mediates further exploration, interpretation, and action in that environment. Empirical support for the absence of such a representation is derived from the absence of trans-saccadic fusion (sect. 5.3) and from the existence of change blindness (sect. 5.10) and inattentional amnesia (sect. 5.10). We claim that this evidence is not compelling.

First, while the notion of trans-saccadic fusion has been disproved (Irwin 1991) the existence of trans-saccadic integration has not. Numerous studies have demonstrated that visual object properties such as orientation (Henderson & Siefert 1999; Verfaillie & De Graef 2000), position (Deubel et al. 1996; Hayhoe et al. 1992), shape (Pollatsek et al. 1984), internal part structure (Carlson-Radvansky 1999), and motion path (Gysen et al. 2002) are encoded on fixation n and affect post-saccadic object processing on fixation $n + 1$. Apparently, the visual system maintains an internal, trans-saccadic representation which codes visual attributes (albeit not on a pixel-by-pixel basis) and impacts subsequent perception. We agree with **O&N** that this representation is not the source of visual consciousness. It often is not even accessible to consciousness (Deubel et al. 1998), yet it is there and it mediates vision.

Second, change-blindness studies appear to provide striking evidence against on-line internal representations, but their relevance for understanding representation as it develops across consecutive fixation-saccade cycles may be limited. First, change blindness disappears entirely when one is warned in advance about the location and type of change that will occur. In contrast, the failure to note certain intrasaccadic changes is resistant to such advance warning, indicating that very different mechanisms are at work. Next, the low detection of changes in change-blindness studies appears to be largely attributable to iconic masking and a failure to deploy attention to insulate iconic contents from masking (Becker et al. 2000). Recent studies using temporary postsaccadic blanking of the visual stimulus have revealed a transsaccadic representation that is very different from iconic memory: Its time course is locked to the saccade dynamics and it does not rely on selective attention to safeguard information from postsaccadic masking (De Graef & Verfaillie 2001a; Deubel et al. 1998; Gysen & Verfaillie 2001).

Related to this last point, **O&N** agree with Wolfe et al.'s (2000) proposal of inattentional amnesia, which holds that we have no online representation of those components of the visual world which we are no longer attending to. Contrary to this view, Germeys et al. (2001) demonstrated location-specific trans-saccadic memory for contextual or bystander objects that are present before, during, and after the saccade to another object. Although it is clear that, prior to the saccade to the target object, these bystander objects were abandoned by attention (if they ever were attended to in the first place), Germeys et al. (in press) found that the bystanders were easier to identify than a new object at the same location. Importantly, this trans-saccadic preview benefit only occurred when the bystander retained its location throughout the fixation-saccade-fixation cycle. This rules out an explanation in terms of priming at the level of stored object representations in a long-term object lexicon and firmly places the effect at the level of an on-line representation of the current visual stimulus.

In view of the above, we want to claim that studies of transsaccadic perception have revealed the presence of an internal rendition of visual aspects of the currently viewed scene. Research on the contents of this representation is still expanding (De Graef & Verfaillie 2001b) but its very existence raises an important question for **O&N**'s sensorimotor account of vision: What is the functional role of this representation in our sensorimotor interaction with the outside world? Perhaps the answer lies in the fact that, by definition, sensorimotor interaction is limited to whatever scene aspect is the topic of transitive visual consciousness (sect. 6.2). Every other scene aspect might as well not be there. Hence, to efficiently apply the right subset of sensorimotor procedures to the outside world to recognize an object (e.g., benefit from a transsaccadic preview), or locate a new visual attribute or explore a new location (i.e., steer attention shifts), some representation is required of where which procedures are most likely to be successful and where we should no longer look.

In conclusion, to not only explain visual consciousness but to also work as an account of vision, the sensorimotor framework should incorporate a more detailed treatment of the on-line visual representations that characterize the transsaccadic cycle. In the absence of this, we could be very happily driving our sensorimotor Porsche in circles or fill it with the wrong type of fuel, neither of which would get us very far.

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Surprise, surprise

Daniel C. Dennett

Center for Cognitive Studies, Tufts University, Medford, MA 02155.
ddennett@tufts.edu ase.tufts.edu/cogstud/

Abstract: The authors show that some long-standing confusions and problems can be avoided by thinking of perception in terms of sensorimotor contingencies, a close kin to my heterophenomenological approach (Dennett 1991). However, their claim that subjects do not have any commitments about the resolution of their visual fields is belied by the surprise routinely expressed by subjects when this is demonstrated to them.

Many tributaries lead into the view of "sensorimotor contingencies" that **O'Regan & Noë** (**O&N**) urge on us, as they are at pains to acknowledge. I particularly applaud their citation of Donald M. MacKay (1962; 1967; 1973) and Gilbert Ryle (1949/1990), two thinkers who were ahead of their time, but did manage to inspire some of the other contributors, myself very much included. It is somewhat surprising that this sensible view, which in its outlines is over half a century old, has not long since been acknowledged to be the mainstream position. But as O&N show, there are powerful misleaders that have prevented it from being more widely accepted. What is especially valuable in O&N's discussion is that they don't just refute the objections: they diagnose their allure in detail, which is the key (one hopes) to preventing another generation of theorists from falling into these traps.

The value added in their detailed presentation of what it means to recast perceptual processes into terms of sensorimotor contingencies, and in their acute discussions of the problems that beset "qualia" objections, "explanatory gap" objections, and the so-called "hard problem," takes us well beyond my own views, which are, as they say, "very similar." Do they also correct an error of mine? I don't think so. They claim (in sect. 7.3) that their method differs from my heterophenomenology in offering a better account of subjects' beliefs about their own experience.

> But is it really true that normal perceivers think of their visual fields this way [as in sharp detail and uniform focus from the center out to the periphery]? Do normal perceivers really make this error? We think not. . . . normal perceivers do not have ideological commitments concerning the resolution of the visual field. Rather, they take the world to be sold, dense, detailed and present and they take themselves to be embedded in and thus to have access to the world.

Then why do normal perceivers express such surprise when their attention is drawn to facts about the low resolution (and loss of color vision, etc.) of their visual peripheries? Surprise is a wonderful, dependent variable, and should be used more often in experiments; it is easy to measure and is a telling betrayal of the subject's *having expected something else.* These expectations are, indeed, an overshooting of the proper expectations of a normally embedded perceiver-agent; people shouldn't have these expectations, but they do. People are shocked, incredulous, dismayed; they often laugh and shriek when I demonstrate the effects to them for the first time. These behavioral responses are themselves data in good standing, and in need of an explanation. They are also, of course, highly reliable signs of their "ideological commitments" – the very commitments that elsewhere in their article the authors correctly cite as culprits that help explain resistance to their view. They themselves point out several times that the various effects their view predicts are surprising. Surprise is only possible when it upsets belief. I think **O&N** need not try so hard to differ with me. If they don't like the awkward term, "heterophenomenology," they needn't use it, but we are on the same team, and they are doing, well, what I think we should do when we study consciousness empirically.

Misperceptions dependent on oculomotor activity

Burkhart Fischer

Brain Research Unit, Albert-Ludwigs-University, Freiburg, D-79104, Germany.
bfischer@uni-freiburg.de http://www.brain.uni-freiburg.de/fischer/

Abstract: Two visual phenomena are described in which oculomotor activity (saccades) changes our conscious perception: (1) some geometrical visual illusions disappear when saccades are suppressed, and (2) misperceptions occur in an antisaccade task with attentional precues. The first phenomenon shows that what we consciously perceive depends on how we look. The second phenomena indicates that a saccade itself may remain unconscious together with the accompanying changes of the retinal image.

The theory of sensorimotor contingency proposed by **O'Regan & Noë** (**O&N**) poses some specific questions in relation to experimental observations. I will discuss here cases of visual illusions in which our conscious perception definitely does not correspond to the physical reality. The critical point is that there are illusions which depend on the way we look at the material that is misperceived: our conscious perception may be right or wrong depending on whether or not the only available sensorimotor actions (saccades and/or attention shifts) are used.

Misperceptions can occur in terms of what we perceive or in terms of where we see a stimulus. Correspondingly, two perceptual phenomena are considered: (1) Some geometrical visual illusions disappear when we look at them the unnatural way (by fixation), instead of the natural way (by saccades). Here, the motor part of vision (the eye movements) create the illusion: what we see consciously depends on how we look (Fischer et al. 2001a). (2) Under certain visual conditions with precued attention, unwanted

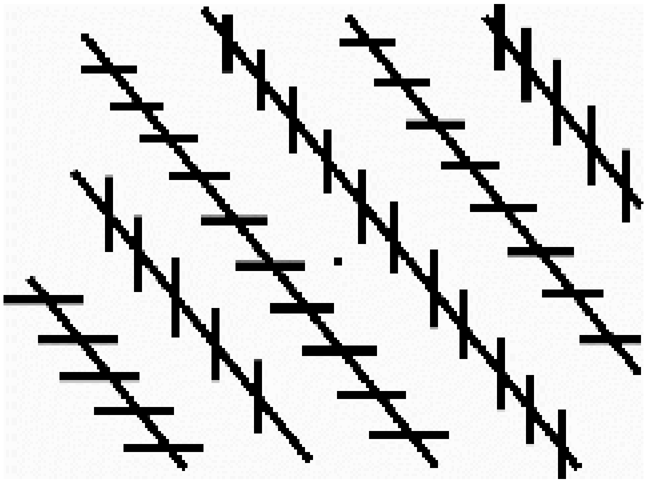

Figure 1 (Fischer). The Zöllner illusion: the long lines do not appear as parallel. Fixate the point in the middle and observe the lines becoming parallel.

reflexive saccades (errors) occur in an antisaccade task (Weber et al. 1998). About half of these saccades and their retinal consequences escape the subjects' consciousness: they are neither reported verbally nor indicated by key press (Mokler & Fischer 1999).

1. The simple geometrical arrangement of lines in Figure 1 show the famous Zöllner illusion: the long lines do not appear as parallel though they are so in reality. The reader may now try to fixate the point in the middle and attend to the lines in the periphery. After some seconds of stationary fixation one clearly sees the lines becoming parallel. No question, both ways of looking – with and without saccades – represent conscious vision. Yet, they lead to different results. Interestingly, it is the saccade mode which leads to the illusion, while the fixation mode results in the correct perception. Scanning through the known geometrical illusions, quite a number of them were found to disappear with stationary fixation (Fischer et al. 2001b). In fact, one may argue that these illusions are not illusions at all, because the visual system as such provides the correct percept. (By the way, it is not clear why these disillusions have escaped the awareness of scientists for more than a hundred years.)

In any case, the exact kind of sensorimotor activity in the actual visual process – saccades or fixation – determines the conscious perceptual result. One could also argue that only inactivity – no oculomotor activity (= fixation) – leads to the correct result. It would be very interesting to see how this observation of geometrical illusions fading with fixation can be incorporated in the theory of sensorimotor contingency. Clearly, a simple neural representation cannot explain the observation unless one introduces an extra mechanism for the geometrical distortion resulting from saccades.

2. The instruction to make saccades from an initial fixation point in the direction opposite of a suddenly presented stimulus is called the antisaccade task (Hallett 1978). One can manipulate the condition so as to make it rather difficult for the subject to follow the instruction: if the initial fixation point is extinguished before a stimulus is presented to the right or left (gap condition), the strength of fixation is diminished and the reflexes become relatively stronger. In this situation subjects generate prosaccades to the stimulus in about 10–15% of the trials (Fischer & Weber 1992). These saccades are unwanted and happen against the subjects' conscious decision.

If the subjects were given a visual precue which indicated the direction and position to which they have to make the next saccade (an antisaccade), the rate of errors increased unexpectedly by a factor of 2 or 3 (Fischer & Weber 1996); even though, according to the classical view, attention should have been captured by the cue and should have facilitated the wanted antisaccade, the opposite happened. In addition, if the subjects were asked to indicate by a key press at the end of each trial whether they believed that they made an error on that trial, 50% of the error saccades escaped the subjects' conscious perception: they denied that they made the error saccade and the corresponding corrective saccade of double size. When the eye movement traces were analysed separately for trials with recognized and unrecognized errors, it turns out that reaction times of the error saccades were the same but the correction times were shorter for unrecognized than for recognized errors (Mokler & Fischer 1999).

Moreover, subjects did not realize that they had been looking at the stimulus for 50 to 200 msec with their fovea. Here we have a twofold misperception: the saccades remained unconscious and the position of the stimulus was misperceived. In those trials the subjects reported a perception of what they wanted to do, not what they really did. They also perceived consciously what would have happened to the stimulus if they had made the correct intended eye movement.

In a few other trials the subjects reported an error but did not make one (false alarm). In these trials the subjects may have shifted their attention to the stimulus and experienced these shifts as saccades. In agreement with the notion that a covered shift of visual attention is a time consuming process the reaction time of these misperceived correct antisaccades were considerably longer than those of correctly perceived correct antisaccades (Mokler & Fischer 1999).

It should be noted that both visual phenomena considered here are independent of any theoretical concept such as, for example, the assumption of neural representations. They are just observations which one way or another should have a place in a valid theory of conscious vision.

Mirror neurons: A sensorimotor representation system

Vittorio Gallese and Christian Keysers

Istituto di Fisiologia Umana, Università di Parma, I-43100 Parma, Italy.
vittorio.gallese@unipr.it keysers@nemo.unipr.it

Abstract: Positing the importance of sensorimotor contingencies for perception is by no means denying the presence and importance of representations. Using the evidence of mirror neurons we will show the intrinsic relationship between action control and representation within the logic of forward models.

The paper by **O'Regan & Noë** (**O&N**) addresses the issue of visual perception from a stimulating perspective, by emphasizing the crucial role played by action in perception. Historically, perception and action have been studied all too separately. A recent instantiation of the intrinsic relationship between action and perception is provided by the discovery of mirror neurons: mirror neurons, although found in motor areas, are endowed with visual properties matching the execution of an action with its perception (Gallese 2001; Gallese et al. 1996; Rizzolatti et al. 1996; Umiltà et al. 2001).

Although the perspective offered by **O&N** is stimulating, we are afraid that the conclusions they draw on mental representations are overstretched. One of their central claims is that there is no need for an inner representation of the outside world. To make their point the authors refer, amongst others, to the work by Lenay (1997) on photoelectric sensing in blind people. In Lenay's experiment, "at a given moment during exploration of the environment, subjects may be receiving no beep or vibration whatever, and yet 'feel' the presence of an object before them. In other words, the experience of perception derives from the potential to obtain changes in sensation." The subjects, having no supernatural way of sensing the presence of the object, must therefore derive their feeling of its presence from some form of knowledge about the object's location. This knowledge, in turn, must derive from past experience. O&N would probably argue that this knowledge reflects mastery of the laws of sensorimotor contingency. But in our eyes, what this implies is that the perception of an object must derive from a representation of it in the brain, albeit not an iconic one.

Indeed, representations in the brain are not thought by visual neuroscientists to be point-by-point picture-like representations. Representations of objects in the temporal cortex, for instance, have been shown to correlate with perception (Keysers et al. 2001), and yet they clearly represent the world in a very abstract, feature-based way, where entire faces are represented by the firing of single neurons, and not by the firing of a set of neurones arranged in the shape of a face. Hence, in our eyes the merit of focusing on the relevance of sensorimotor contingencies for perception – in contrast to what **O&N** suggest – is not to falsify the importance of representations for perception but to help us understand the nature of these representations. In particular, it points towards the fact that representations may take the form of forward models of motor consequences (see Kawato 1999; Wolpert 1997; Wolpert et al. 1995). Mirror neurons may be examples of forward models as representations (Gallese 2001): they respond, for instance, to the sight of a hand action and to the intention to execute it. Hence, they may constitute a system that can predict the sight of the agent's hand action when planning to move its hand – and thereby their activation also constitutes a "visual" representation of a hand action. This representation can be used not only to control your own actions, but also to perceive those performed by others. Visual representations and motor representations may thus be two sides of the same coin (Gallese 2000). By this account, representations are not an end but a means: the payoff of the necessity to anticipate, and therefore re-present, the consequences of a planned action in order to control it better. How else could we know that our intended action is going wrong if we didn't have an inner representation of what it should look like? Ironically, in a way mirror neurons instantiate both the very expertise of sensorimotor contingencies so central to O&N's theory, and the representation of the world, the importance of which O&N argue against.

These representations are not the result of a solipsistic monadic organism, but rather the result of the active and dynamic interplay of the organism with its environment and the control requirements of this interplay.

In conclusion, we think that stressing the importance of sensory motor contingencies in perception is not antagonistic to the notion of an inner representation of the world, but rather a way to help us understand how such representation may be achieved and why it exists.

Real action in a virtual world

Melvyn A. Goodale

Department of Psychology, University of Western Ontario, London, Ontario N6A 5C2, Canada. **mgoodale@uwo.ca**
http://www.sscl.uwo.ca/psychology/faculty/goodale/

Abstract: O'Regan & Noë run into some difficulty in trying to reconcile their "seeing as acting" proposal with the perception and action account of the functions of the two streams of visual projections in the primate cerebral cortex. I suggest that part of the problem is their reluctance to acknowledge that the mechanisms in the ventral stream may play a more critical role in visual awareness and qualia than mechanisms in the dorsal stream.

Who couldn't be enthusiastic about **O'Regan & Noë**'s (**O&N**'s) proposal? They have managed to push the idea of "seeing as acting" much further than many of us might have thought possible. All those thorny problems – representation, consciousness, qualia – vanish from sight as soon as one realizes that vision is more about doing than seeing and that our percepts are more virtual than real.

The central concept of **O&N**'s proposal is that seeing is a specific way of exploring the environment. There is no need to posit a detailed internal representation of the outside world; vision arises because of the perceiver's knowledge of the sensorimotor contingencies that are jointly determined by the visual apparatus and the visual attributes of objects. The idea that perception is a grand illusion and that the external world represents itself is an attractive one – but there are still some issues with respect to experiential perception and the visual control of action that are only partially addressed in O&N's otherwise compelling thesis.

O&N's treatment of the ventral-dorsal story is particularly unconvincing. They begin by arguing that the double dissociation in deficits following lesions of the dorsal and ventral streams poses no problem for their "seeing as acting" idea. But then they go on to say something rather curious. "Seeing" they say "is an activity depending on a range of capacities, for example, capacities for bodily movement and guidance, on the one hand, and capacities for speech and rational thought on the other." Thus, they argue, it is not surprising that these capacities "can come apart" and that the dorsal stream "can operate in relative isolation from the ventral stream."

But what does this mean? Are they harking back to the point that they raised earlier in the article, that visual awareness depends on both mastery of sensorimotor contingencies and the use of this mastery in one's planning, reasoning, and speech? Do they want to associate the sensorimotor part of this equation with the dorsal stream and the reasoning part with the ventral stream? But if so, then it would be difficult to reconcile this idea with the pattern of deficits seen in patients with ventral or dorsal stream damage. If visual awareness depends on both sensorimotor contingencies and the ability to use the mastery of these contingencies for rational thought then patients should lose visual awareness with lesions of either the dorsal or the ventral stream. But we know that this is simply not the case. Patients with ventral-stream damage are much more likely to lose visual awareness of particular visual attributes than are patients with dorsal-stream damage. Patients with dorsal-stream damage, who may have lost a good deal of visuomotor control, are still quite aware of the shape, size, orientation, and location of objects that they see (for review, see Goodale & Milner 1992; Milner & Goodale 1995). In other words, there is something about visual processing in the ventral stream that is more intimately associated with seeing than is processing in the dorsal stream.

But alternatively, perhaps **O&N** mean to say that the activity of seeing – visual awareness – supports both the guidance of action and the guidance of thought. Thus, according to O&N, the visual-agnosia patient DF, who suffered ventral-stream damage, has partial visual awareness of form. As they put it, DF "is unable to describe what she sees, but she is otherwise able to use it for the purpose of guiding action." But this distinction does not capture the profound nature of DF's problem. It is not that she cannot talk about what she sees; she cannot perform the simplest of visual discriminations of form. She cannot, for example, distinguish horizontal from vertical lines or tell if two simple geometrical shapes are the same or different. But at the same time, she has excellent visual imagery for form and is also able to draw familiar objects and shapes from memory (much like a blind person might do). Moreover, she can readily identify an object using haptic exploration. What she appears to lack is any conscious appreciation of the visual form of objects. Yet when she reaches out to grasp objects that vary in size, shape, and orientation, her grasp is oriented correctly and the posture of her moving hand reflects the geometry of the object well before she makes contact with it. In short, she shows nearly perfect visuomotor control in the absence of any evidence that she actually "sees" the form of the object she is grasping.

To construe DF's profound deficit in visual perception (and her spared visuomotor abilities) as "partial awareness" or as an "[inability] to describe what she sees" is to distort what is normally meant by awareness or even visual qualia. DF does not have any visual experience of form. But the fact that DF has an absence of visual awareness can perhaps be used to bolster **O&N**'s thesis. After all, according to them visual awareness is a joint product of the mastery of sensorimotor contingencies and the use of this mastery in one's thought and planning. The ventral stream is certainly well positioned to carry out the latter. It has intimate connections with regions in the temporal lobe and prefrontal cortex that mediate long-term memory and higher executive functions – just the sort of connections one might expect to see in a system that plays a critical role in the production of a virtual percept imbued with meaning and causality.

(I might add parenthetically that **O&N**'s attempt towards the end of their paper to map the apparatus-related sensorimotor contingencies onto the dorsal stream and the object-related sensorimotor contingencies onto the ventral stream just doesn't fly. Mastery of object-related contingencies plays an essential role in skilled visuomotor actions, such as grasping, which are mediated by dorsal-stream structures and which typically survive damage to the ventral stream and sometimes even damage to primary visual cortex. Moreover, there is neurophysiological and imaging evidence that areas in the dorsal stream code object properties, such as size, orientation, and three-dimensional structure, and that these same areas play a role in the visual control of object-directed grasping [for review, see Goodale & Humphrey 1998].)

I would like to end by saying that I found this to be a thoughtful and provocative account of vision and visual consciousness. I suspect, however, that like most boldly stated ideas in science, it will attract a lot of flak. But if it does only that it will be doing the field a considerable service.

Visual perception is not visual awareness

Valerie Gray Hardcastle

Science and Technology Studies Program, Department of Philosophy, Virginia Tech, Blacksburg, VA 24061-0227. **valerie@vt.edu**
http://mind.phil.vt.edu

Abstract: O'Regan & Noë mistakenly identify visual processing with visual experience. I outline some reasons why this is a mistake, taking my data and arguments mainly from the literature on subliminal processing.

O'Regan & Noë (**O&N**) present us with an exciting and original view of visual perception. Moreover, their view has the ring of truth about it. This is all good and I applaud the authors. But in this commentary I wish to focus on their attempt to connect their views of visual perception with conscious experience. Here things are more dubious. In particular, O&N fall into the same trap that many others before them have fallen into – they equate a new view of some aspect of cognition or perception with a new view of consciousness. It must be an easy and comfortable intellectual slide, since so many intelligent people make it. But there is much about perception that isn't conscious and there is much about consciousness that isn't perception. Knowing more about how our visual system operates can, of course, tell us important things about how consciousness must operate as well, but it is a real stretch to claim that the two processes are identical.

O&N claim that in achieving visual awareness, we use our mastery of the relevant sensorimotor contingencies for the purposes of thought and planning. As a result, experience does not derive from brain activity per se, but it consists in the "doing" itself. Both claims are false.

There is a huge and often contradictory literature out there regarding unconscious visual perception. Unfortunately, most of the research has been directed to determining whether subliminal perception exists at all, and not to what exactly we can process outside of awareness and how much such processing affects decision-making or behavior. But it is not premature to draw some conclusions. First, we know that unconscious visual perception exists. We have known this since the late 1880's; just a few curmudgeons have refused to accept the obvious. Second, we are coming to appreciate how much we can in fact process outside of awareness. Not only can we recognize abstract properties such as "open" or "closed" in novel shapes (Hardcastle 1996), but we also can uncover complex arbitrary patterns (Lewicki et al. 1987; 1992; Stadler 1989). More importantly, what we perceive unconsciously affects how we decide – it affects how we process sensorimotor contingencies and then it affects how we move through space.

For example, Hanna and Antonio Damasio concern themselves with the differences in rule-following between normal subjects and frontal lobe patients (Bechara et al. 1997). What is interesting about their research, though, is the task itself, for what counts as advantageous motor behavior in a board game is highly relative and depends heavily on how the players interpret their visual inputs. Subjects are given four decks of cards and are instructed to pick a card from any deck. They are "rewarded" or "punished" (using Monopoly money) according to which deck the card came from and the face value of the card. Subjects, however, are not told what the reward strategy is. They are simply allowed to chose as they see fit. What we learn from experiments like this is that we move advantageously before we are aware of our strategy for motor choice, before we are aware of the relevant sensory patterns.

Notice that to understand what counts as a correct choice in the Damasios' experiment requires some serious interpretation of the face value of the cards vis-à-vis the instructions given concerning the fake money. If we respond unconsciously to the rules of the game, then our unconscious must be processing possibilities for intelligent behavior on the basis of semantically interpreted visual information.

From this quick example, we can see that while visual processing might consist of mastering relevant sensorimotor contingencies, such mastery can occur both inside and outside of awareness. Hence, consciousness must be something over and above visual processing simpliciter. It might be that we need consciousness in order to process visual information robustly, but that is a different claim and one **O&N** don't make. Let us suppose that O&N are correct and that visual processing turns on appreciating how we can move through space. Since we are conscious of a subset of what we process visually, understanding how our brains and our bodies define sensorimotor contingencies is relevant to understanding awareness, even if the two processes aren't identical. It is in this sense, perhaps, that O&N mean that conscious experience consists in the doing itself. Without the possibility for movement, we wouldn't have vision and without vision, we wouldn't have visual consciousness. So far, so good. But none of these considerations allows us to disconnect experience – or vision – from brain activity.

If we are materialists (which I am assuming here), then conscious experience has to be identical to some material event in the world. It might be true that much of what we experience is illusory – we see the world as a broadly continuous movie, when our perceptions are actually more like tiny, discrete snapshots. Nevertheless, the illusion has to have some substrate. These are all obvious points, but they require that, insofar as we believe that the brain processes sensory information (regardless of whether such information is intimately tied to our motor system), then our visual processing, and hence our visual awareness, have to derive from brain activity. It might not be the activity that we normally assume, nor might it be located where we think it is, nor might it be theoretically fruitful to consider such activity apart from the rest of our body. But on pain of dualism, the experience has to derive from what the brain is doing, albeit an active brain embedded in a challenging environment.

In the Mind's Eye: Perceptual coupling and sensorimotor contingencies

Julian Hochberg
Columbia University, New York, NY 10023. **hochberg@columbia.edu**

Abstract: The theoretical proposal that perceptual experience be thought of as expectancies about sensorimotor contingencies, rather than as expressions of mental representations, is endorsed; examples that effectively enforce that view are discussed; and one example (of perceptual coupling) that seems to demand a mental representation, with all of the diagnostic value such a tool would have, is raised for consideration.

This paper by **O'Regan & Noë** (**O&N**) marks a new and powerful approach to perception, to cognitive neurophysiology, and to the perceptual technology so pervasive in our lives. Although the approach has close predecessors, this is the most economical yet comprehensive and far-reaching version I know.

The paper's essential points are these: Vision is an exploratory behavior, not the activation of internal representations of the things and layout of the world, and what we perceive results from our acquisition of the principles of sensorimotor contingency. As the authors note, this position's power lies in the exceptional range of behavior for which it accounts. (I would add: and it helps that it is essentially correct.) I think it can do more than that: It offers a potentially much more inclusive and complete approach that, as Thomas (1999) notes in his PA (Perceptual Activity) view of imagery, has relatively recent close relatives in Hebb (1947; 1968), Hochberg (1968), Neisser (1967), Sperry (1952), and others, but for various reasons has not really taken off until now. **O&N** now offer a more systematic and unencumbered framework than we have previously had. Indeed, if we fill in a few points not addressed in the paper, the position becomes even more impressive and enormously promising, although the notion of sensorimotor contingencies becomes somewhat more abstract than it first sounds.

The fact that only the small amount that can be encoded in working memory survives for approximately 200 msec after a glance is taken (Sperling1960) stresses the importance of extrafoveal vision as a (low-frequency-sensitive) storage of what was seen and of what is potentially available to another glance (see Hochberg 1997; 1998; O'Regan 1992). Phenomena like that in Figure 1 tell us that local information as basic as the object's 3D form may not only go unencoded between glances, but when out of central vision may be both ineffectual and uninformative of what would be seen if fixated. Knowledge of such limitations will help us to dissect what naively seems a seamless perceptual experience. That apparent seamlessness is probably due, among other things, to the normal prevalence of intraobject consistency (what you learn from one part of an object will usually serve for the whole); and a reluctance to do unnecessary checking. The variations on the modified Penrose figures in Figure 1C, D, when they are thought about (Hochberg 1968), make all of these points; the argument that they are uninformative because ecologically improbable, is hard to apply in a world in which at least so much of our time must be spent with computer-generated displays.

Such figures, and the study of how successive views are stored and grasped in motion pictures, led me to argue that (as **O&N** note) our perceptions are "the program of possible samplings of an extended scene, and of contingent expectancies of what will be seen as a result of those samplings" (Hochberg 1968, p. 323).

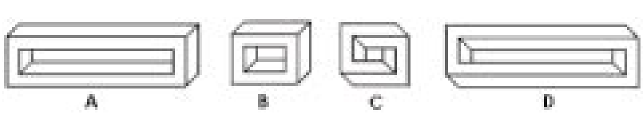

Figure 1 (Hochberg). Variations on Penrose figures (A, B: Possible; C, D: Impossible); only C looks grossly inconsistent as a 3D object (Hochberg 1968).

But that means we need to study the nature and motivation – that is, attention – of such contingent expectancies, *and their limitations.* Such attention is neither a glue, a spotlight, nor a filter: It does not require a filter to obscure the unattended channel in a shadowing experiment (i.e., an experiment in which the listener who is duplicating one speaker's monologue cannot report what another speaker has said), only a failure to be ready with a set of expectations with which to encode the words spoken before they fade from the immediate moment (Hochberg 1970). Liberman (1957) had argued that listening requires *analysis-by-synthesis:* the testing of attended speech against internally intended speech, so listening to speech also meets the sensorimotor-expectancy description. From this standpoint, skilled reading also calls on the production of constrained expectancies, which makes proof-reading very difficult, and makes inattention to omissions and errors so common. Inattentional blindness to the things and events in the world is not a new problem: Similar attentional dependence has been demonstrated in perceiving the contents of superimposed motion pictures (Neisser & Becklen1975) and in the kind of sequential partial views ("aperture viewing") on which so much of our virtual visual world of moving pictures depends (Hochberg 1968; Hochberg & Brooks 1997).

Attention, at least in this most engaged and powerful sense, is not separable from the constraints on sensorimotor expectations, and this point is challenged when the objects of our perceptual inquiry are *not* simply derivable from the natural ecology of the physical world. In responses to the natural world, inter-response constraints, like size and distance, reflectance and form, and so on, may be attributable to the world rather than the observer. Such constraints were called *perceptual coupling* (Hochberg 1974) specifically to avoid any implication that one percept necessarily causes the other, and to avoid attributing Helmholtzian inference to the nature of perceptual expectations. They can be demonstrated and studied with still and moving pictures as well as with real depth, even though there are no sensorimotor depth-based contingencies present either in the pictures or in the visual system. If the sequence of silhouettes in Figure 2C is preceded by the pattern in Figure 2A, 3D motion is perceived with Arrow I showing the leading edge; if Figure 2B precedes the sequence in 2C, Arrow II is what is seen as the leading edge in motion – so long as A and B are clearly perceived as 3D forms (Hochberg 2001).

That may imply an "internal mental representation" of the first figure. However, the perception of 3D form is itself a sensorimotor contingency, though that contingency here would not be depth-based even if it played out. One set of contingencies may surely preset another. But there is more to be formalized and set in theoretical order for sensorimotor contingencies than meets the eye.

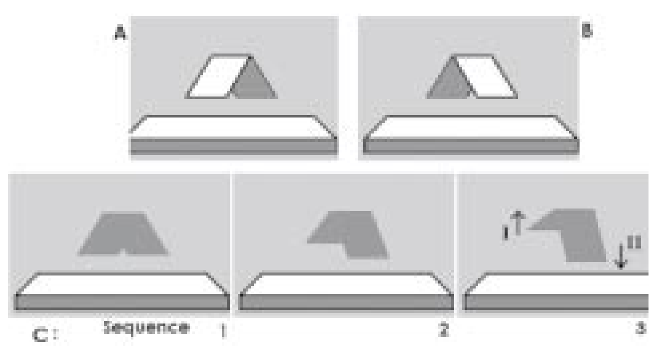

Figure 2 (Hochberg). Pre-exposure to the 3D picture at A or B determines the apparent motion in depth of the sequence of flat silhouettes at C (Hochberg 2001).

Doing it my way: Sensation, perception – and feeling red

Nicholas Humphrey

Centre for Philosophy of Natural and Social Science, London School of Economics, London WC2A 2AE, United Kingdom.

n.humphrey@lse.ac.uk **www.humphrey.org.uk**

Abstract: The theory presented here is a near neighbour of Humphrey's theory of sensations as actions. O'Regan & Noë have opened up remarkable new possibilities. But they have missed a trick by not making more of the distinction between sensation and perception; and some of their particular proposals for how we use our eyes to represent visual properties are not only implausible but would, if true, isolate vision from other sensory modalities and do little to explain the phenomenology of conscious experience in general.

O'Regan & Noë's (**O&N**'s) theory of visual consciousness has several parallels with the theory I proposed ten years ago (Humphrey 1992; 2000). In my book, *A History of the Mind,* I argued, from first principles, that sensations (of all kinds, not only visual) derive their characteristic phenomenology from the fact that they are – in evolutionary origin – a kind of bodily action, involving reaching back to the stimulus at the body surface with an evaluative response. "Conscious feeling. . . is a remarkable kind of intentional doing. Feelings enter consciousness not as events that happen to us but as activities that we ourselves engender and participate in" (Humphrey 1992, p. 217). In particular, I suggested that the modality-specific quality of sensations is determined by what I called the "adverbial style" of the responses associated with different sense organs. Drawing on a musical analogy, I suggested that each type of sense organ has, as it were, to be played like a musical instrument in its own way: "fingered, blown, bowed, plucked, etc. . . . so that the tactile modality might correspond to the woodwind style, the visual modality to the strings style, and so on" (p. 165).

I went on to argue then, just as **O&N** do now, that such an "action-theory" of sensations is uniquely able to account for *what it's really like* to experience red light at the eyes, taste salt on the tongue, and so on; and, indeed, that it can dispel many if not all of the mysteries surrounding qualia. I thought it was a good theory at the time; and I think O&N's version of it is a good theory now. However, the way O&N have developed the idea of "seeing as action" goes far beyond what I did. Their thesis is brilliant and provocative – in several ways more radical than mine, but not, I think, entirely an improvement. I'll restrict my comments to two aspects of their presentation.

Sensation and perception. In making my own case I began with the insight, stemming from Thomas Reid, about the essential difference between sensation and perception (Reid 1785/1969). "The external senses," Reid insisted, "have a double province – to make us feel, and to make us perceive" (p. 265). Sensation is the way the subject represents "what's happening to me" at the level of bodily stimulation, perception is the way he represents "what's happening out there" as a description of the outside world. "Things so different in their nature," Reid had said, "ought to be distinguished" (p. 249).

Now, **O&N** do at least pay lip-service to this distinction, acknowledging that: "Sensation consists in those sensorimotor contingencies that are modality-specific, determined by the laws of contingency provided by the particular apparatus used in a particular modality, and by the particular way the apparatus samples the world. Perception consists in knowing those laws that are related to the object" (O'Regan, personal email). But, as O'Regan goes on, "we don't want the distinction to be hard and fast." And, indeed, they fail to see that they are – or should be – talking about two *independent types of experience.* Consequently, O&N end up making just the kind of category mistakes that so many other theorists have done – as Reid warned they would, – when they have assumed that seeing (or hearing or touching. . .) is all of a piece.

This is particularly obvious when it comes to their attempts to explain those "exceptions that prove the rule," such as skin vision, perceptual rearrangement, change blindness, and blindsight. In all these cases people's reported experiences have, as I've shown, a simple explanation if we assume that sensation and perception can – and here indeed are – going their own ways. But **O&N**, not having a model that allows for this kind of disassociation, are instead driven to engage in complex and unconvincing special pleading about what people's experience actually amounts to in these strange conditions.

***Sensorimotor* – what?** I myself proposed an "action theory" only for sensation. I confess it did not occur to me that perception might be action-based as well (although back in 1970 I had suggested that the residual visual capacity of a monkey without visual cortex might in fact be mediated by – and secondary to – her "looking-behaviour," Humphrey 1970). But I am ready to agree that what works on one level may indeed work on another, and that actions are probably crucial to most if not all aspects of how we use our sense organs. So I now find many of **O&N**'s specific suggestions very persuasive.

Yet their central example, of how we perceive (or is it sense?) redness, I find unconvincing. We experience something as red, they say, by virtue of exploring (or anticipating exploring) how the responses of our anisotropic retinae change when we move our eyes in relation to the image. I can see how this might work for a small localised patch of red light with clear contours. But how about the case where the visual field is coloured red all over? In this case, when we move our eyes, *nothing changes.* And yet, of course, we are still able to see it as red – suggesting that here we must in fact be relying on the steady retinal signal *per se,* independently of any action on our part.

I also have a worry of a more general kind. Even if this sort of account *can* be made to work for colour, it's hard to see it being made to work for equivalent dimensions in other sensory modalities that do not have such *actively-explorable* anisotropic fields. When we taste salt on our tongues, or smell musk in our noses, or feel pain in our stomach, how can *these* experiences plausibly be thought to depend on sensorimotor contingencies? There is simply nothing we *do by way of exploration* with our tongues (or our noses or our stomachs. . .) that could provide requisite information. But, if exploratory action cannot provide the answer in these non-visual cases – and so, as theorists, we must invoke some *other* active process – why not invoke a similar process (whatever it is) for seeing red too?

What other kind of active process could underlie sensation in general? My own view is that the key lies not so much with sensorimotor *contingencies* as with sensorimotor *proclivities,* and that the kind of action involved is not *exploration* of the stimulus but rather *affective engagement* with it. In short, if I may simplify it so, while **O&N** would argue that when we sense a stimulus this is the way *it feels to us* because this is how *we plan to feel it,* I would argue that this is the way *it feels to us* because this is how *we feel towards it.*

Still, these are local disagreements between myself and **O&N**. In the longer run, I'd rather emphasise how much I admire the spirit of their paper. It has been well said that *pour se disputer, il faut être en accord.* (That's to say, the best arguments are between those who share their premises).

How do we account for the absence of "change deafness"?

Frédéric Isel
Max Planck Institute of Cognitive Neuroscience, Leipzig, Postfach 500 355, D-04103 Leipzig, Germany. **isel@cns.mpg.de** **http://www.cns.mpg.de**

Abstract: O'Regan & Noë (O&N) argue that there is no need of internal, more or less picture-like, representation of the visual world in the brain. They propose a new approach in which vision is a mode of exploration of the world that is mediated by knowledge of sensorimotor contingencies. Data obtained in "change blindness" experiments support this assumption.

This commentary focuses on **O'Regan & Noë**'s (**O&N**'s) proposal that we do not necessarily "see" everything that we are looking at, but rather, we only see what we are currently attending to. Change blindness experiments demonstrate that, under arranged experimental conditions (for example, when superimposing a very brief global flicker over the whole visual field at the moment of the change) observers who were asked to detect cyclically repeated large changes in a natural visual scene (for instance, the shift of a large object, the change of color, or the appearance and disappearance of an object) have difficulties in noticing these changes. This outcome suggests that either observers are not *aware* of all the elements in the visual scene (e.g., they neglect some elements) or the high expectations of an element could lead to its restoration even though it was previously removed from the scene (e.g., a hallucinated element). However, as mentioned by **O&N**, under normal circumstances a change of this type would create a transient signal that would be detected by low-level visual mechanisms. Therefore, it is important to point out that change blindness only occurs in some experimental situations.

Another example of change blindness is illustrated by the difficulty in detecting unexpected information. Haines (1991) and Fisher et al. (1980) who tested eight professional pilots during the landing of aircraft in a flight simulator, showed that two of the eight pilots were unable to detect an unexpected jet airplane that was located directly ahead of them on the runway. Taken together, evidence of change blindness is fairly discouraging with respect to current theories that assume the storage of a picture-like representation of the world in some area of the brain. If such visual representations do exist, one should expect the processing system to be able to detect the presence of a "large" mismatch between the stored representation of a scene and its "truncated" input signal when it is re-presented. Given the size of this mismatch, the output of the processing system should be either a correct detection of the missing element, or an unsuccessful identification of the scene. On the contrary, change blindness strengthens the view proposed by **O&N** that observers lack *visual awareness* of many of the aspects of a visual scene, and that the world serves as an outside memory. However, one can ask whether change blindness is modality-independent and can also be found in other sensory domains?

I will now argue that behavioral and electroencephalographical data obtained in the auditory domain clearly indicate the ability of the cognitive system to detect missing elements in words (deletion of a phoneme) as well as in sentences (deletion of a word). I will try to demonstrate that change blindness, which I call "change deafness" in the auditory domain, is not systematically found.

Although Warren (1970, Experiment 1) showed that the replacement of a phoneme in a recorded sentence by a cough resulted in the illusory perception of the missing sound, other data invalidate the phenomenon of change deafness. Warren (1970, Experiment 3) failed to replicate a phonemic restoration when a speech sound was deleted and not replaced with an extraneous sound. In this latter condition, participants were able to perfectly detect the gap in its proper location and illusory perception of the missing sound did not occur. This outcome does not support the idea that any missing element of an "auditory scene" can be either restored or overlooked, even when this element is highly expected. Rather, it suggests that the processing system is sensitive enough to detect 120 msec of gaps in a word. In language comprehension also, there is evidence against change deafness. Recent event-related brain potentials (ERPs) data on syntactic processing do not agree with the view that missing words in a sentence are simply restored or neglected. Friederici et al. (1993) in German, and Isel et al. (1999) in French, showed that the suppression of the noun in prepositional phrases (e.g., the noun *house* in the sentence *the child who is in the house is sleeping*), is a phrase structure violation that elicits an early left anterior negativity (ELAN) assumed to reflect the on-line assignment of a syntactic structure to the incoming information on the basis of the word category. The short latency of the ELAN (around 100 to 300 msec after the acoustic onset of the item following the missing noun) indicates that the syntactic processor is able to rapidly detect the absence of elements presenting the appropriate word category with respect to the grammatical constraints of the sentence. The ELAN is usually followed by a late centroparietal positivity (P600) assumed to reflect a reanalysis process once the syntactic violation has been detected. Moreover, in both studies, behavioral data showed that participants were able to perform the task of grammatical judgment without any error indicating that they were *aware* of the change in the syntactic structure. The ELAN/P600 pattern observed in correlation with syntactic word category violations demonstrate that the electrical activity of the brain is significantly modified in some area when expected elements of a sentence are deleted.

In conclusion, in the auditory domain, evidence at word as well as sentence levels suggests that change deafness is not systematically found. Regarding detection of changes, it seems that the cognitive system does not behave similarly in the visual and in the auditory modalities. Whereas large changes in visual scenes can be neglected by observers, a small gap in spoken words or the deletion of a word in a sentence are clearly noticed by listeners. On the basis of the data we presented for auditory processing of changes, the assumption that words and syntactic properties are represented in the brain is not unplausible. In contrast, the data of change blindness presented by **O&N** are intriguing because they considerably weaken the concept of stored picture-like representations in the brain usually proposed in current neurophysiological, psychophysical, and psychological approaches. Hence, the sensorimotor account presented in the target article opens new perspectives.

The role of eye movements in perception

Nam-Gyoon Kim
Department of Psychology, William Paterson University, Wayne, NJ 07470. **kimn@wpunj.edu**

Abstract: For Gibson, sensory stimulation is neither the cause nor a component of perception, but merely incidental. Perception is based on the pickup of information, which occurs when purposeful observers actively seek information. I present a case in which only with the active sampling of the ambient optical flow field can observers extract the requisite information for the control of locomotion.

As a Gibsonian ecological psychologist, I was extremely pleased with **O'Regan & Noë**'s (**O&N**'s) target article in which they denounced mental representation as "mysterious or arcane explanatory devices" for explaining visual experience (see sect. 13). I am very sympathetic to their attempt to provide a natural account for this elusive problem. Indeed, this was exactly the problem that led Gibson to develop his ecological approach to perception. Gibson's solution, however, was remarkably different from O&N's.

Gibson came to understand perception as an *exploratory activity.* He rejected the idea that inputs of any sort could be relevant to perception. Sensation may occur when stimulation is *imposed,*

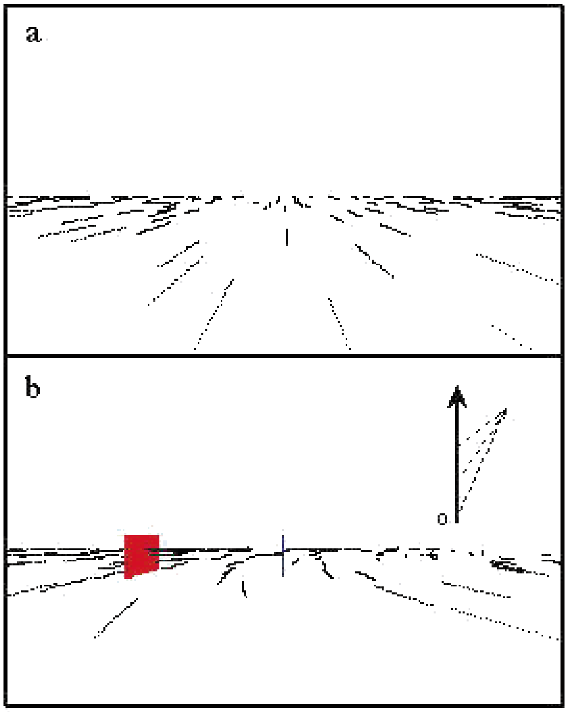

Figure 1 (Kim). Retinal flow corresponding to translation along a linear path (a) with the focus of expansion and (b) under pursuit fixation.

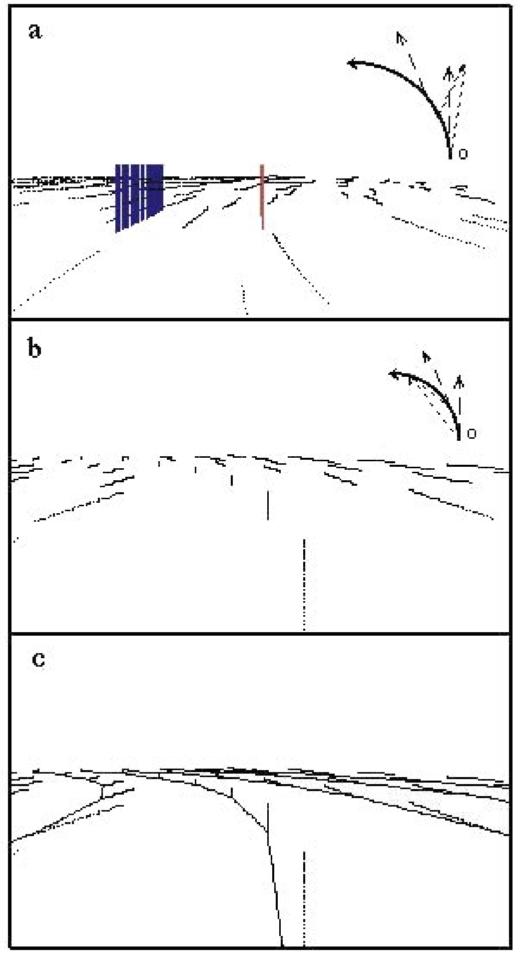

Figure 2 (Kim). Retinal flow corresponding to translation along a circular path with pursuit fixation on an object lying (a) outside or (b) on the path. (c) In a linearized retinal flow field, the path constructed from the vertical vectors identifies the observer's path of locomotion. See Kim & Turvey (1999) for further details. The geometries of the observer's path, tangential heading, and gaze direction are shown by solid, long dotted, and short dotted arrows, respectively.

but not perception. Perception occurs only when purposeful observers actively seek stimulation. Thus, Gibson's psychology is not just a theory of ecological information specific to environmental properties but includes the active role played by the observer in search of goal-relevant information.

In this commentary, I present a case of exploratory activity that renders a seemingly intractable problem tractable. I focus on *optical flow,* a particular change in optical structure that results from an observer's locomotion and constitutes the primary basis for visually guided locomotion (e.g., Warren 1995). For example, when an observer moves straight ahead, the *focus of expansion* in the resultant optical flow corresponds to the direction of locomotion (Fig. 1a). To move directly toward an object, one need only keep this singularity coincident with the object.

However, when an observer looks around, sampling different portions of the ambient optical flow, the image pattern on the retina (retinal flow) changes. For example, as a forward moving observer tracks an object, the eyes rotate and the point of fixation becomes the singularity instead of the focus of expansion (Fig. 1b). Thus, even though information about heading direction is available in optical flow, there is no guarantee that the observer can extract it when needed (Regan & Beverly 1982).

If the observer proceeds along a curved path, even the well-defined radially expanding pattern generated by an observer walking straight ahead disappears. Worse yet, the observer may not always look in the direction of locomotion, further complicating the flow pattern. Consequently, an informational basis for perceiving heading is needed that is not specific to a particular locomotion path.

Computer simulations can help. Graphic simulations depicting an observer moving along a circular path are quite different when the eyes are fixated on an object lying outside the circular path (Fig. 2a) or on the path (Fig. 2b). When the fixated object lies on the path, all image trajectories are linearized.

In circular locomotion, observers' paths are specified by the optic flow line passing directly beneath them (Lee & Lishman 1977). This line is easily identified by the trajectory of all the vertically aligned image vectors (Fig. 2c). Because rectilinear locomotion is a special case of circular locomotion, any method of identifying heading on a circular path can be applied to a rectilinear path. Hence, we can formulate a simple rule to identify one's (linear or circular) heading: *Move the eyes until the image trajectories are rendered linear; then you are looking in the direction you are headed towards and the trajectory defined by the vertical image vectors is your path of locomotion.* In short, by actively rotating the eye, the observer can recover the ambient optical flow field from image motion.

If the visual system has to differentiate various types of eye movements, the task may be insurmountable (cf. Warren 1995). However, if each movement is recognized as an outcome of a unique intention, the unique pattern in retinal flow can be exploited. We may fixate and pursue an object during locomotion to learn more about it; but in so doing, we risk reducing our directional awareness from absolute to nominal (Kim et al. 1996). Because we have frontal eyes, our field of view is restricted to a small portion of the optical flow. To avoid collisions with objects outside our field of view, we must continuously scan our surroundings, which may necessitate using unreliable extra-retinal signals to determine heading (Royden et al. 1994). Therefore, with each type of eye movement, we may both gain and lose something (e.g., directional awareness). However, when directional awareness is required, we can compensate by executing a simple rule, that is, scanning until retinal flow becomes linear. The fact that drivers concentrate their fixations in the direction they head (Shinar 1978) corroborates this hypothesis.

The preceding discussion offers possible solutions to age-old questions. First, how can a series of discrete samples of the world be converted to a stable and continuous visual world (e.g., Irwin 1991)? If the coincidence of gaze and heading directions during locomotion collapses retinotopic and environmental frames of reference, there is no need for conversion processes and various stages of frames of reference. Paradoxically, in fixed-eye vision, retinal pattern changes with shifts in eye position; but ambulatory vision simplifies the problem, resulting in a stable and continuous visual world (see also Ballard 1992). Extending the preceding point, imagine that you are a passenger in a car. By actively rotating your eyes to induce a linearized retinal flow, you can pick up the same information as the driver, that is, the driver's intended heading direction – despite the fact that your "sensations" are completely different than the driver's. Here we have a clue as to how to understand the sharing of awareness between different observers. As Gibson (1982a) noted, "your perception and mine can be identical even though your sensation and mine can never be identical at the same time. The same invariants are available to us both" (pp. 411–12).

Why rotate our eyes if rotation induces ambiguity? Based on the arguments presented here, active rotation of the eyes is essential for extracting the self-movement information contained in optical flow. Strategically positioning the eyes renders a nonlinear flow linear. "Problems that are ill-posed and nonlinear for a passive observer become well-posed and linear for an active observer" (Aloimonos et al. 1988, p. 333).

Consciousness as action: The eliminativist sirens are calling

Martin Kurthen

Department of Epileptology, University of Bonn, D-53105 Bonn, Germany.
martin.kurthen@ukb.uni-bonn.de **http://www.epileptologie-bonn.de**

Abstract: The sensorimotor theory of vision successfully blends in with the currently developing action-oriented account of cognition. As a theory of phenomenal consciousness, however, it suffers from the same shortcomings as the theories O'Regan & Noë (O&N) criticize. This is mainly due to the failure to avoid the explanatory gap by rejecting one notion of qualia while retaining the concept of experience with qualitative features in general.

Two problems of consciousness. Let's take **O'Regan & Noë**'s (**O&N**'s) theory of vision as a part of a more general sensorimotor theory of cognition (STC). In their approach to consciousness, O&N address *two* problems. The first one is that, according to a widespread intuition, an account of the neural correlate of consciousness does not really make the "hard problem" of explaining phenomenal consciousness any easier. The second one is that any theory of consciousness will have to explain the "differences in the felt quality" (target article, sect. 1.2) within one modality and across sensory modalities. The latter problem is elegantly solved by O&N's notion of modality-specific sensorimotor contingencies, but this solution presupposes some prior solution (or dissolution, or rejection) of the first problem. At best, the proposal concerning the second problem can be embedded in a more comprehensive conceptual framework of embodied cognition that – combined with a certain preference in coping with the qualia problem (eliminativist, agnostic, pragmatic, deconstructionist. . .), – could *as a whole* suggest a rejection of the first problem. But O&N are not willing to adopt any of these combined approaches. The sensorimotor contingency framework *alone, as part of a neurobiological or ethological theory of vision,* however, will not "allow for the explanation. . . of a good deal of what makes the subjective character of experience" (sect. 2.7), because it *presupposes* that an organism's contingency-governed action somehow generates or constitutes phenomenal consciousness in the first place (see below).

The nature of experiences. In an (unwillingly?) eliminativistic tone, **O&N** maintain that "qualia are an illusion" (sect. 6.3). To reject the notion of qualia means to reject the notion of phenomenally conscious tokens or features in favor of *whatever the alternative theory invokes* (in O&N's case, in favor of "activity"). But in common usage, "phenomenally conscious features" *are* "experiential features." Hence, it remains unclear how O&N could both dismiss qualia as an illusion *and* keep with qualitative features of experience, as they are explicitly willing to do. I assume that O&N do not understand "experience" non-phenomenally, for this would render their approach eliminativistic from the start.

O&N address this problem in their critique of the view that qualia are *states* or *occurrences of something.* They hold that qualia *in the sense of states/occurrences* are "an illusion," but they keep with the "qualitative character" of experiences (*as* ways of acting). But what could it mean that experiences *"are"* ways of acting? Either there are phenomenal features of experiences, or there aren't. If there are, then the gap opens between these features and the ways of acting they are meant to be identified with. If there aren't, we have landed at the eliminativist or deconstructionist shore once again. There is no third path to follow, unless you argue that the *whole notion of phenomenal consciousness* (not only that of phenomenal consciousness *as* occurrences/states!) is somehow ill-designed and has to be "quined" (Dennett 1991). But O&N explicitly reject this move, which anyway has a manifestly eliminativistic flavor, too.

To clarify the origins of the "qualia illusion," **O&N** present a phenomenological analysis of experience (sect. 6.4) in which they show that, contrary to the assumptions of some qualia freaks, the factual phenomenological aspects of experience do not support the notion of qualia *as* (sensation-like) occurrences, internal representations, or "unitary" qualities in general. In their examples, O&N nicely illustrate that their action-oriented theory fits well with the actual phenomenology of experience. And again, in O&N's own view this merely invalidates the construction of qualia *as states or occurrences,* not the notion of qualitative features of experience as such. But they don't seem to see that for the qualia freak, this does not help to close the gap: in their own words, it may be made plausible that the phenomenal features of experience are "constituted by" (sect. 6.3) or "depend on" (sect. 6.4) the "sensorimotor contingencies at play." This move opens the gap just like any other "constitution hypothesis" would: why is it that sensorimotor contingencies at play generate – or constitute – phenomenal features at all, instead of being just that: sensorimotor contingencies in an organism-environment system? Why is it that skillful mastery of contingencies *is* experience, instead of being just that: skillful mastery? (By the way, this is exactly what O&N's action-oriented phenomenological analysis of experience [sect. 6.4] suggests: that *there is nothing* "over and above" skillful mastery of sensorimotor contingencies.)

Action alone will not close the gap. In passages like these, it becomes obvious that **O&N** literally identify consciousness qua experience with law-governed action (see sect. 5.7) without any independent argument for this identification. In this respect, they don't do better than the representationists (or neural-correlate-of-consciousness-theorists) they criticize. By merely *postulating* an identity of action and visual consciousness, they will not escape the explanatory gap problem, since "ways of acting" are by no means closer to experiential features than "internal representations" are. O&N clearly anticipate this objection (sect. 6.8), and they reject it in the overtly eliminativistic manner they had applied before when they had stated that "qualia are an illusion" (sect. 6.3). And again, they want to keep with "experience" (and hence qualia, in some sense or other!) while dismissing qualia *as* states/occurrences. But the gap argument is not dissolved or avoided by just rejecting *one* "conception of experience" (sect. 6.8): the gap remains *whenever* the existence of "experience" with "qualitative character" is conceded in the context of a neurobiological approach to consciousness. In O&N's example, it remains unclear in which sense the feeling of holding a bottle could *be* the "knowledge that movements of the hand open up and reveal new aspects of bottle surface" (sect. 6.8). "Knowledge" cannot be construed as a conscious mode of cognizing here, for that would render the explanation circular; what is meant is something like "skilled exercise." But then the question O&N pose in the introduction (ridiculing neural-correlate-of-consciousness-theories of consciousness) is still left unanswered in their own approach: why should skilled exercise generate phenomenal consciousness at all? The only way out is the straightforwardly eliminativistic one that declares the whole notion of there being something to explain as illusory (or the radically deconstructionist one which holds that consciousness itself can be subject to social deconstruction; see Kurthen et al. 1998). And there is no reason why the STC should not be used to promote strategies like these.

A sensorimotor theory of cognition, not of consciousness. **O&N** may well be right in arguing that the STC overrides the traditional representationist paradigm in cognition theory. There are quite a number of good philosophical and scientific reasons for this (see Hendriks-Jansen 1996, Lakoff & Johnson 1999, and Pfeifer & Scheier 1999 for current reviews), some of which O&N do not need to employ directly for their own approach. As for vision, one aspect of the superiority of the STC is its elegant account of the modality-specific aspects of vision in terms of sensorimotor contingencies. But this gives no clue whatsoever to the desired dissolution of the explanatory gap: to dismiss qualia in favor of ways of acting will not suffice to avoid the gap as long as the existence of experiences with qualitative character is affirmed.

Does sensorimotor contingency theory account for perceptual-motor dissociations?

Francesco Lacquaniti and Myrka Zago

Human Physiology Section, Scientific Institute Santa Lucia and University of Rome "Tor Vergata," 00179 Rome, Italy. **lacquaniti@caspur.it m.zago@hsantalucia.it**

Abstract: We review studies that indicate a dissociation between the perceptual estimate and the resulting cognitive representation of given properties of a seen object, on the one hand, and the motor action exerted on the same object. We propose that there exist multiple levels of organization of sensorimotor loops and that internal models may be made accessible to one level of organization while remaining inaccessible to another level.

In the on-going debate between supporters of sensorimotor affordances and supporters of internalization of world physics (see *BBS* Special Issue on THE WORK OF ROGER SHEPARD), it is apparent that neither factor alone can account for the whole repertoire of human behavior in sensorimotor coordination. Dissociations between perception and action seem especially difficult to reconcile with unifying explanations. Some interesting examples of such dissociations are provided by the study of interaction with moving objects. There are two aspects of interest here: visual perception and cognitive judgment of object motion, on the one hand, and motor interception on the other hand.

Consider the case of projectile motion, such as a baseball hit by a batter. Object trajectory is nearly parabolic with horizontal velocity which decreases steadily by a small amount due to air resistance, and vertical velocity which decelerates from the release value to zero at the apex of the trajectory and then accelerates downwards under the action of gravity. Despite the fact that throwing and catching balls is a generally practiced skill, cognitive and perceptual understanding of this simple ballistic motion is surprisingly poor. Hecht and Bertamini (2000) used a number of different approaches to study the explicit and implicit assessment of projectile acceleration by an observer. Many subjects mistakenly believed that the ball would continue to accelerate after it left the thrower's hand and showed a remarkable tolerance for highly anomalous trajectory profiles in computer graphics animation.

A related issue is whether or not visual perception of the absolute size and distance of a moving object could be disambiguated by taking into account the expected effects of gravity (Saxberg 1987; Watson et al 1992). Once again, however, Hecht et al. (1996) showed that observers do not behave as if they made use of some knowledge about gravity. Projectile motion of balls of different diameters and at different distances from the observer was simulated on a computer. Performance was compared with two categories of events, accelerating balls and constant-velocity balls. It was found that observers are as bad at scaling absolute size and/or distance of accelerating balls as they are with constant-velocity balls. In sum, these and similar studies seem to suggest that the naive physics used by the brain in the assessment of ballistic motion does not account for Newton's laws.

The opposite conclusion can be reached if one considers tests of motor performance instead of perceptual tests. Subjects can catch or throw with great spatial and temporal accuracy (Alderson et al. 1974; Peper et al. 1994; Sharp & Whiting 1974). Moreover, it has been shown that the acceleration of a falling ball is predicted quite accurately to prepare motor responses (Lacquaniti 1996; Lacquaniti & Maioli 1989a; 1989b; Lacquaniti et al. 1993a; Tresilian 1993; 1999). It has further been hypothesized that the specific acceleration of gravity can be foreseen based on an internal model (Lacquaniti 1996; Lacquaniti & Maioli 1989a). Gravity is a terrestrial invariant that is monitored by several sensory systems and the consequences of its effects on objects can be learned through experience. This hypothesis has been tested in a series of studies involving catches of free-falling balls of identical external appearance but different mass, dropped from heights between 0.2 and 1.6 m (Lacquaniti et al. 1992; 1993a; 1993b; Lacquaniti & Maioli 1989a; 1989b). The electrical activity (EMG) of arm muscles was recorded. The time to onset of anticipatory activity relative to impact and the time course of the activity do not change with the height of fall, nor do they depend on the ball mass. Thus, the responses are precisely timed on impact time. A similar time-locking on impact is observed for the modulation of muscle reflex responses and for the changes in overall hand impedance. Remarkably, motor preparation of reflex responses and limb impedance is correctly timed on impact even when blindfolded subjects are alerted of ball release by an auditory cue (Lacquaniti & Maioli 1989b). Not only is the response timing tuned to gravity, but also the magnitude of the anticipatory responses is tuned to the expected momentum of the incoming ball (Lacquaniti & Maioli 1989a; Lang & Bastian 1999). Thus, even though Newton's laws may not be internalized for constructing a visual representation of the object's motion, they seem to be internalized for manual interception of the object.

A striking dissociation between cognitive/perceptual assessments and motor interaction with a moving object has recently been shown in micro-gravity studies (McIntyre et al. 2001). Astronauts caught a ball projected from the ceiling at different, randomised speeds. Despite the prolonged exposure to 0g, the information given by vestibular organs, pressure cues on the skin and visual cues from objects floating within the cabin – all clearly attesting the micro-gravity conditions in orbit, – the astronauts did not believe their eyes that told them the ball was travelling at constant velocity. Instead, to catch the ball they gave credence to an a priori model of the physical world in which a downward moving object will always accelerate. In fact, their motor activity always started too early at 0g, with time shifts in accord with a 1g hypothesis.

According to the sensorimotor contingency theory put forth by **O'Regan & Noë** (**O&N**), seeing and perceiving are a way of acting on the environment. It is not obvious how the theory can explain perceptual-motor dissociations. Moreover, O&N reject the idea that there exist internal representations of the outside world. A general purpose, unifying theory may assume just one level of organization of sensorimotor loops, whereas it is more likely that there exist multiple levels. Perceptual and cognitive events may be constructed using building blocks different from those used for motor reactions. What is available at one level may not be available at another level. Thus, the data we reviewed above do indicate that physical laws are internalised in the brain, and that these internal models may be made accessible to one level of organization while they remain inaccessible to another level.

On the distinction between "sensorimotor" and "motorsensory" contingencies

Donald Laming

Department of Experimental Psychology, University of Cambridge, Cambridge CB2 3EB, United Kingdom. **drjl@cus.cam.ac.uk**

Abstract: An experimenter studies "sensorimotor contingencies"; the stimulus is primary and the subject's response consequential. But the subject, looking at the world from his or her distinctive viewpoint, is occupied with "motorsensory contingencies"; the response is now primary and the sensory consequential. These two categories are gathered together under the one term in the target article. This commentary disambiguates the confusion.

The term "sensorimotor contingencies" is serving a double duty. Suppose I conduct an experiment – I impose a large, cyclically repeated, change on a natural scene, masking the temporal transient (though not the change), and ask my subject to say what is being changed. That studies a sensorimotor contingency. Now suppose my subject is running an eye over the scene I propose to use. As his (or her) eye moves, so the projection of a straight line on the retina is distorted. That is, properly speaking, a motorsensory contingency. The distinction is essential. When I analyse my data I regress my subject's reports onto the various ways in which I have attempted to mask the change. But if my subject were to analyse the effects of eye movements in any formal sense, that analysis would be a regression of the sensory change onto the (motor) movement that produced it. In the first case the independent variable is a stimulus (my choice of mask), in the second it is a response (the subject's choice of eye movement). These two sets of contingencies are entirely disjoint, and it follows that my experiment can tell me nothing about my subject's internal visual experience.

Motorsensory contingencies induced by the visual apparatus can be inferred from the optics of the eye and are much the same for everyone. Likewise, geometrical considerations lead to an understanding of many contingencies determined by visual attributes. Moreover, by serving as a subject in his own experiment, an experimenter can check his intuition in such matters. But that does not give access to another person's visual experience. The fact that I am aware of the change I have imposed on my natural scene tells me nothing about whether my subject is also aware!

The point to be grasped is that subject and experimenter experience the experiment from two contrary viewpoints. What is, to the experimenter, a dependent response, predictable (to some extent) from the stimulus, is, to the subject, an independent variable, a choice at his disposal. Consciousness is the quality of experience from the subjective viewpoint and is forever beyond the ambit of strictly experimental study.

An analogy will help here. If I look out from the window of my breakfast room, I can see three other houses, separated from me by a road and a green sward. If a car comes to turn round in the road (it is a cul-de-sac), my neighbour and I can readily agree that the car is red. That arena outside our houses is a part of the public domain within which objective experiments can be conducted. But my neighbour and I cannot see into each others houses because the light reflected from the windows is much too bright. I can telephone my neighbour, but I can then only describe the interior furnishing of my breakfast room by comparison with things that my neighbour will have seen elsewhere. The scope of experimental procedure can be extended to internal experience only by projecting that experience into the public domain. This is accomplished by my selecting elements within that domain that would generate, if I were actually viewing them, my current visual experience. But there is a limit to the accuracy with which I can express my state of mind. If I describe my curtains as scarlet, or carmine, or cerise, or plum, or. . . – my neighbour might think of a different external colour referent to the one that I have in mind, and "seeing red" will then mean slightly different things to the two of us. Of course, I can invite my neighbour into my house to see for himself; but I cannot give him direct access to my visual experience. Visual experience is private to each one of us, and that is why visual awareness presents a problem.

Many visual scientists think they can crack that problem with neurophysiological observation. Visual experience is a function of the brain; a sufficient complexity of observation and understanding (but much greater complexity than anyone has at present) will enable a direct access to my visual experience. There are four problems with this view.

1. An experimenter cannot know what I am aware of unless I tell him. So neuroscientific understanding will be limited to the relationship between neural process and verbal (or some other mode of) report. That will be satisfactory if my report is both accurate and complete; but is it?

2. The processes inside my brain divide functionally into two categories. There is the state of mind that I am reporting and there is the function of observing that state of mind and reporting on it, a function on which I am ultimately unable to report. It happens that my house is built to a plan that is different from any of the three others I can see across the way, but I cannot observe that difference from my breakfast room window because I cannot see the exterior of my house. The observer cannot see himself as others see him.

3. In addition, there are many lower level functions – the initial processing of visual input is one – that are not accessible to consciousness and cannot be reported on. So the neuroscientist has a much greater variety of observations of my brain processes than can be matched to my reports, and experiment is needed to sort those observations that do match something from those that do not.

4. But we now return to the problem with which I began. The neuroscientist can study detailed contingencies between sensory input and neural response, but that is no more than a detailed kind of sensorimotor contigency. My reports, on the other hand, relate to what I can do, to what I choose to do, and concern motorsensory contingencies. The two categories do not correspond. The question: which aspect of my verbal reports relate to which aspects of neurophysiological observation, can never be more than a matter of conjecture, even though some of those conjectures may seem very plausible.

Attention sheds no light on the origin of phenomenal experience

Victor A. F. Lamme[a] and Rogier Landman[b]

[a]*The Netherlands Ophthalmic Research Institute, AMC, University of Amsterdam, 1105 BA Amsterdam, The Netherlands;* [b]*Department of Visual System Analysis, AMC, University of Amsterdam, 1100 AA Amsterdam, The Netherlands.* **v.lamme@amc.uva.nl**
r.landman@ioi.knaw.nl **http://www.ioi.knaw.nl**
http://www.ioi.knaw.nl

Abstract: In O'Regan & Noë's (O&N's) account for the phenomenal experience of seeing, awareness is equated to what is within the current focus of attention. They find no place for a distinction between phenomenal and access awareness. In doing so, they essentially present a dualistic solution to the mind-brain problem, and ignore that we do have phenomenal experience of what is outside the focus of attention.

What causes the phenomenal experience of a visual stimulus? The traditional view is that at successive stages of visual processing, information that is embedded in the input is made explicit by neurons, either individually, by selective firing when this information is present, or as a group, with a particular "neural code" such as synchrony. Neurons make explicit a lot of attributes of the visual input, ranging from elementary features to high level inferences such as illusory contours, filling-in, scene segmentation, colour constancy, and so on. Damage to such neurons results in a loss of the experience of these attributes, while artificial stimulation leads to the occurrence of an experience. Explicit representation is considered necessary for phenomenal experience, but not sufficient. Some additional property, either of the neural activity, or of the areas in which it occurs, is assumed to be necessary. This is the "quest for the neural correlate of consciousness (NCC)" (Crick & Koch 1998; Lamme et al. 2000).

O'Regan & Noë (**O&N**) propose a different basis for phenomenal experience. They argue that correlations between neural activity and the reported percepts should not be taken to indicate that neurons are building an internal representation of the world. Rather, they are involved in the mastery of certain sensorimotor contingencies related to dealing with the visual input. In this view, explicit representations are not necessary. This is a potentially useful interpretation of the neural data (although very difficult to validate), but does it solve the mind-brain problem?

Much of the brain is devoted to sensorimotor transformations that fully bypass phenomenal experience (Stoerig 1996). Mastery of sensorimotor contingencies also includes making inferences, an important aspect of perception. Neural activity related to perceptual aspects (i.e., those which have to be inferred from the input) can be recorded when animals are anesthetized (Gray et al. 1989), do not pay attention to stimuli (Assad & Maunsell 1995), or report not to see stimuli (Super et al. 2001). This implies that the sensorimotor contingencies mastered by these neurons at that time are not sufficient for awareness, while at other times they are. The question remains open: What causes *some* masteries of sensorimotor contingencies to give rise to awareness, while others do not? It seems we are in for another quest for the NCC.

The key, according to **O&N** is that some masteries are made available for control, thought, and action, while others are not. What would this mean at the neural level? Visual input resulting in the firing of motor neurons ("action") is obviously insufficient (cf. blindsight, automatic behavior, etc.). So the solution lies in finding the neural basis of "thought" and "control," and then figuring out how the interaction between visual and control mechanisms is represented at the neural level. Much of this work has already been done in the study of the neural basis of attention (Desimone & Duncan 1995). However, O&N refute such explanations as they would constitute an "analytic isomorphism." But what other than a specific set of neural events renders a mastery into a current mastery?

We believe, therefore, that equating phenomenal experience to the current mastery of sensorimotor contingencies does not explain phenomenal experience at the neural level, and essentially constitutes a dualistic view of the mind-brain problem. However, this is only the first of our problems. We also think that the authors are looking for awareness in all the wrong places.

Top-down attention seems central to the notion of current versus other masteries. It is argued that "casting one's awareness onto what is made available by the visual apparatus" (sect. 4.1) is what makes a mastery a "current mastery." On the basis of change blindness and inattentional blindness phenomena it is even concluded that without top-down attention there is no awareness. But what do these phenomena really show?

In a change blindness experiment, a visual scene is presented, followed by a modified version of that scene (while local transients are masked in one way or another). Much of the contents of the first scene seem lost, as we do not notice a potentially salient difference between the two unless we focus attention on the changing item. But does that imply that there was only poor phenomenal experience of the first scene? Recent experiments show that memory of the original stimulus is quite extensive until the modified version of the stimulus comes on. When attention is guided by a cue after the offset of the original picture and before onset of the modified version, change blindness is largely eliminated (Becker et al. 2000). Change blindness occurs because the representation of the original stimulus is overwritten as soon as a new stimulus comes on. What is then left of the original scene is what has been transferred to working memory, a process requiring attention.

When we rely on a report about the subjects' phenomenal experience we are essentially looking at their memory of it. We thus have to face the difference between working memory and so called iconic or sensory memory, a short lived form of memory, that is richer, yet less stable, than working memory (Cowan 1988; Sperling 1960). There is no scientific reason to exclude either of the two from a theory about awareness. By the same token, there is no reason to eliminate the very related distinction between phenomenal and access awareness (or P-consciousness and A-consciousness; Block 1996).

We conclude that equating phenomenal experience to the current mastery of sensorimotor contingencies puts no challenge to more traditional views on the NCC. We conjecture that visual experience is caused by the recurrent interaction of neurally explicit visual information, which can be reported as soon as this information is linked to the executive systems of the brain (Lamme 2000). The sensorimotor theory is an interesting and inspiring view. However, it leaves us with the questions of why some masteries of sensorimotor contingencies give rise to awareness while others remain unconscious, and which are the neural events that cause the masteries to give rise to awareness. Also, because phenomenal awareness is eliminated at the expense of access awareness, it is more a theory about attention and working memory, than about the origin of phenomenal experience.

Does functionalism really deal with the phenomenal side of experience?

Riccardo Manzotti and Giulio Sandini

LIRA-Lab, DIST, University of Genova, 16145 Genova, Italy.
manzotti@lira.dist.unige.it **sandini@dist. unige.it**
http://manzotti.lira.dist.unige.it **http://www.lira.dist.unige.it**

Abstract: Sensory motor contingencies belong to a functionalistic framework. Functionalism does not explain why and how objective functional relations produce phenomenal experience. O'Regan & Noë (O&N) as well as other functionalists do not propose a new ontology that could support the first person subjective phenomenal side of experience.

In reading **O'Regan & Noë**'s (**O&N**'s) paper two major concerns are mandatory. First, it is difficult to see in what respect the authors' standpoint is different from functionalism. Second, it is difficult to define objectively what sensory motor contingency (SMC) is without recourse to some kind of external interpretation.

The authors reject the representational framework advocated by several other authors (Kosslyn et al. 1995; O'Brien & Opie 1999), according to which conscious perception derives from the instantiation of structures somehow similar to external objects. We agree with **O&N** that this approach has several serious problems, among which are: (i) apart from geometrical spatial relations, how can the other qualities of experience (colour, smell, sound) be reproduced? (ii) there is no compelling evidence of the existence of such structures; (iii) if such structures were found there is no *a priori* or scientific theory showing why their presence in the brain should result in some subjective qualitative experience.

The authors correctly address all these three issues. To overcome these difficulties they propose "a different approach" whose "central idea is that vision is a mode of exploration of the world that is mediated by knowledge of" what they call "sensorimotor contingencies" (target article, sect. 1.3). In itself this is not a strong claim since it has already been made several times, most notably by functionalism. In fact, the authors claim that "seeing is a way of acting": a statement that could be accepted from a functionalist (if not behaviourist) standpoint. Nevertheless, it is not clear what is the novelty of SMCs with respect to other forms of functionalism. If we have understood the authors' standpoint, a SMC is a set of compelling correspondences between action and perceived objects. Yet the authors do not provide a general proof of the fact that every visual conscious phenomenal object can be reduced to SMCs. Even if these SMCs could be located, the authors do not explain why these SMCs, which – by their own admission – are just "rules governing the sensory changes produced by various motor actions" (sect. 2.1), should correspond to phenomenal experiences. The authors should have realized that something is missing when they wrote that "the visual qualities are determined by the *character* of the SMCs set up by the visual apparatus" (sect. 2.3). A series of questions arises: i) if visual qualities are determined by SMCs, then what are visual qualities? are they something different from SMCs? ii) what is the character of a SMC? Is it something different from a SMC in itself? iii) what are the laws connecting visual qualities and SMCs? iv) it seems perfectly conceivable that SMCs exist without any visual qualities or phenomenal experiences at all, then why should SMCs explain subjective experience?

Although the empirical data collected by **O&N** can be very helpful in building a functionalistic theory of vision and in giving a more complete explanation of the way information is processed by the brain, it does not help in explaining why such information processing should be correlated to a conscious experience. The authors do admit the existence of such a gap between SMC and consciousness and they promise to provide more details in section 6.

In section 6, the authors are adamant in stating their functionalist credo that phenomenal experience does not exist as a real phenomenon. According to them, the "qualia debate rests on what Ryle . . . called a category mistake" (sect. 6.3). They write that their position does not deny that "experience has a qualitative character," yet it seems to deny the existence of experience in itself. "It is confused to think of the qualitative character of experience in terms of the *occurrence* of something. . . . Experience is something we do and its qualitative features are aspects of this activity" (sect. 6.3). Unfortunately, there are no qualitative aspects available. Since what we do, from a strict objective standpoint, is just a series of physical events there is no quality at all. We do not accept this functionalist credo and hold a different standpoint. The idea that subjective facts are real has gained wider and wider acceptance (Chalmers 1996a; Edelman 1987; Edelman & Tononi 2000; Manzotti & Tagliasco 2001; Stubenberg 1998). Leopold Stubenberg makes a straightforward statement about this concept in what he calls *the principle of phenomenological adequacy.*

> I will reject everything that does not square with what I take to be the phenomenological data. . . . "So much the worse for phenomenology" is not a viable option for one who adheres to the principle of phenomenological adequacy. Phenomenology is what the theory of consciousness is supposed to illuminate. If a theory requires us to disregard the deliverances of phenomenology then it is not the theory I seek .

The authors' claim that the explanatory gap can be filled "because it does not really exist" is not acceptable outside a functionalistic framework.

In conclusion, our main criticism is directed towards three issues. First, it is not clear what the difference is between the SMC approach and functionalism. Second, we do not see why the existence of SMCs should entail any phenomenal experience. Third, we do not see what is the ontological status of such SMCs (are they intrinsic properties of matter? do they entail consciousness even when they occur in an artificial machine? are they sufficient to let consciousness emerge?). Yet, the authors' approach is valuable in that it marks the possibility of locating consciousness outside the brain. The repeated failure in the search for a neural correlate of consciousness can thus be used as a suggestion for a different approach that includes the relations with the external environment. Although **O&N**'s approach does not directly address the problem of consciousness, it can be the basis for a more radical attempt to locate the phenomenal properties of experience in a broader framework than that of internalism. But functionalism cannot be enough.

Sensorimotor contingencies do not replace internal representations, and mastery is not necessary for perception

Ernst Niebur

Zanvyl Krieger Mind/Brain Institute and Department of Neuroscience, Johns Hopkins University, Baltimore, MD 21218. **niebur@jhu.edu**
http://www.cnslab.mb.jhu.edu

Abstract: Sensorimotor contingencies are certainly of great importance for perception but they are no substitute for the internal representation of perceived information. I argue that internal, non-iconic representations of perceptions must, and do, exist and that sensorimotor contingencies are an integral part of them. Further, I argue that mastery of the sensory apparatus or environment is not a prerequisite for perception and that perception is possible in the absence of any control over the perceptual process.

Sensorimotor contingencies are important for internal representations, not for "movie screens." **O'Regan & Noë** (**O&N**) spend a large part of the target article elucidating how the perceiver makes use of "sensorimotor contingencies." This is a laudable and important endeavor. Even students of neuroscience sometimes may wonder why we don't perceive, for example, saccadic smear.[1] The detailed treatment in the target article makes it clear that (a), sensorimotor contingencies are an essential part of what it means to see, and (b), they are not "mysterious" in any way.

The second dragon they are trying to slay is the idea of an internal "movie screen" and, implicitly of course, the homunculus who watches it. Although the need is less clear in this case – I suspect few serious thinkers still entertain the notion of a *camera obscura* inside the brain which the external world is projected into – all their arguments are correct. For instance, they demonstrate convincingly (perhaps most so through O'Regan's beautiful work on change blindness) that the outside world serves as its own representation for many of the perceived details, and that they are *not* reproduced in the internal representation. The brain does not internalize a detailed, iconic representation of a visual scene since it is readily available at the (minimal) cost of opening the eyes; it would be very inefficient to build up a costly detailed representation that can be had nearly for free.

However, in fighting the idea of an internal movie screen, the authors go way too far and deny the existence of *any* internal representation. This is in contradiction to the results of essentially all electrophysiological studies of sensory perception. In a classic example, nearly 40 years ago Hubel and Wiesel (1962) showed that visual presentation of an oriented line leads to characteristic firing patterns in primary visual cortex, with cells varying their firing rates as a function of the stimulus orientation relative to their preferred orientation. Clearly, this pattern of cellular responses is part of the *internal representation* of the oriented bar. More complex stimuli are represented in ways that are poorly understood. The iconic form available at the photoreceptor level is not suitable for at least some of the important tasks the brain has to perform during perception. It needs transformed representations that are better suited than the raw iconic input (available to the brain i*n addition* by accessing the outside world) for establishing meaningful relationships between ecologically important stimuli, for efficient access to memory (storage and retrieval), and so on. These transformed representations incorporate sensorimotory contingencies like the visual "artefacts" of iconic representations, for example, the "saccadic smear." Whatever the details of the internal representation are, and whatever are the underlying reasons why this particular representation is implemented in the brain, there can be no doubt that there *is* a representation of sensory input.

"Mastery" is not perception. The authors claim that awareness is intimately related, or even identical, to the instantaneous "mastery" of sensorimotor constraints. There are many counter examples to this claim. For instance, let us consider a hypothetical situation in tactile perception. Assume that you are holding a three-dimensional lump of matter, like a mass of modelling clay, that is somehow moved by internal actuators in a complex, unpredictable way, without you having any possibility of influencing or predicting its motion and the forces it exerts on your hands (i.e., there is no "mastery"). According to the claims of the target article, the lump should not be perceived since the perceiver does not interact with it in "lawful" ways. This seems absurd; the lump will surely be perceived, and probably quite vividly so.

This idea is not entirely hypothetical. A two-dimensional version, consisting of a few hundred probes that touch the skin, that can be moved independently and, therefore, can emulate any surface within a wide parameter range, has actually been built and is used to provide dynamic tactile stimuli to both humans and monkeys (Vega-Bermudez & Johnson 1999). When set to "random" mode, the stimulation patterns are completely unpredictable but, of course, they are perceived.

Analogous examples can be constructed in all modalities. In vision, imagine random flashes of light being projected directly onto parts of the retina; they will certainly be perceived even though the activation they generate in the optic nerve does not follow "lawful" rules. A simple example from the auditory system is listening to music through headphones: Many of the sensorimotor contingencies are removed (turning of the head will change neither amplitude nor frequency nor synchrony between ears) but the symphony is still perceived.

One might argue that part of the sensorimotor contingencies is the interaction between different sensors (e.g., lateral inhibition between neighboring retinal ganglion cells) and the resulting patterns they project onto the cortex. Such interactions are presumably intact even when random patterns are presented to the sensory periphery. This argument is easy to refute. We have no control at all, let alone mastery, about cortical phosphenes, yet they are clearly perceived. Another example: From experiments pioneered by Penfield it has been known for a long time that direct electrical stimulation of the cortex gives rise to (sometimes vivid) perceptions, yet it is hard to imagine a perceiver with less mastery over his or her perceptual environment than a patient with an opened skull receiving electrical stimulation directly to his or her cortex.

NOTE

1. Another example: The second edition of Kandel and Schwartz (1985), *the* standard textbook for teaching neuroscience well into the 1990s, explained that we perceive the world in the correct orientation because the "upside-down" projection of the retinal image is "compensated for" by "higher levels of the brain" (p. 358).

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A sensory-attentional account of speech perception

Howard C. Nusbaum,[a] Jeremy I. Skipper[b] and Steven L. Small[b]

[a]*Department of Psychology, The University of Chicago, Chicago, IL 60637;* [b]*Departments of Psychology and Neurology and the Brain Research Imaging Center, The University of Chicago, Chicago, IL 60637.*

h-nusbaum@uchicago.edu skipper@uchicago.edu s-small@uchicago.edu http://home.uchicago.edu/~slsmall http://www.ccp.uchicago.edu/faculty/Howard_Nusbaum/

Abstract: Although sensorimotor contingencies may explain visual perception, it is difficult to extend this concept to speech perception. However, the basic concept of perception as active hypothesis testing using attention does extend well to speech perception. We propose that the concept of sensorimotor contingencies can be broadened to sensory-attentional contingencies, thereby accounting for speech perception as well as vision.

We see the world by knowing what to expect when we move our visual system through the environment. This is the heart of **O'Regan & Noë**'s (**O&N**'s) account of vision. Furthermore, they argue that sensorimotor contingencies underlie all perception, not just vision. In this commentary, we examine the limitations upon the extension of sensorimotor contingencies to speech perception and suggest that a broader, more general concept – sensory-attentional contingencies – may explain perception in different sensory modalities.

Although **O&N** allude to hearing, they do not really explain auditory form perception. But, sensorimotor contingencies are unlikely to mediate auditory form perception – motor movements only subserve hearing for source localization and play no role in understanding speech. Since speech patterns "move" in frequency space over time, we don't need to wiggle our ears or move our head to avoid "static displays" or stabilized images that disappear (as by O&N for vision).

This eliminates a prime motivation for sensory-motor contingencies, leaving two possible conclusions. Either speech perception operates according to traditional representation-matching theories, or we need a more abstract version of sensorimotor contingencies. This abstraction should maintain the principles of sensorimotor contingencies without tying the theory to motor movements.

O&N view perception as active, knowledge-based, and hypothesis-driven. Knowledge of sensorimotor contingencies drives visual experience through the deployment of attention in the visual world. But is it the motor behavior or the exploratory sensory contingencies that are the core concept? In vision, active hypothesis testing may be carried out in the motor system by moving sensory surfaces in relation to the physical surfaces of the environment. However, speech perception can be viewed as active hypothesis-testing (see Nusbaum & Schwab 1986) without involving the motor system. Speech perception cannot be explained by positing simple pattern representations of linguistic categories to be matched to utterances (Nusbaum & Henly 1992) because there is no stable set of properties that can be assigned to those putative categories (see Nusbaum & Magnuson 1997). We have proposed instead that listeners construct hypotheses about the linguistic categories that would account for a particular stretch of utterance given the context of the situation and expectations of the listener (Nusbaum & Schwab 1986). These hypotheses are tested by shifting attention to the relevant information to constrain interpretation. For example, when there is a change in talker, there is a momentary increase in cognitive load and a shift in attention to acoustic properties such as talker pitch and higher formant frequencies (Nusbaum & Morin 1992).

O&N describe sensorimotor contingencies as specific to characteristics of the visual apparatus and the visual attributes of objects and scenes. In speech perception, sensory-attentional contingencies depend on the characteristics of the auditory apparatus and linguistic experience of the listener. However, sensory-attentional contingencies also depend on phonetics and phonology for determining constraints on the "form" of speech objects and the acoustic characteristics of the talker and environment for instantiating that form in a pattern.

Since talkers and speaking characteristics restructure the acoustic patterns of linguistic forms (Liberman et al. 1967), sensory-attentional contingencies cannot be stored as fixed knowledge but must be adaptive and dynamic. Adult listeners learn new acoustic-phonetic patterns for hard-to-understand synthetic speech rapidly and effectively – eight hours of learning improves word identification by about 40 percentage points (Schwab et al. 1985) generalized to novel utterances (Greenspan et al. 1988; Schwab et al. 1985) lasting as long as six months without subsequent training (Schwab et al. 1985). Training shifts the way listeners attend to acoustic cues (Francis et al. 2000) reflecting the induced sensory-attentional contingencies. Similarly, when someone new starts talking, listeners know how to shift attention to acoustic properties to accommodate talker differences (Nusbaum & Morin 1992). Adaptive processing of speech is marked by attentional movements rather than by motor movements.

We might think that the "motor" in sensorimotor contingencies refers to articulation. But listeners do not subvocalize to understand speech, and neural activity in Broca's area occurs when listeners are called upon to hold items in verbal working memory (subvocal rehearsal) tasks (see Jonides & Smith 1997), or when they must make explicit metalinguistic judgments (e.g., Burton et al. 2000; Zatorre et al. 1992). Without a directed linguistic task, speech generally activates the posterior superior temporal cortex (Binder et al. 2000; Burton et al. 2000; Rep et al. 1996), even though motor theory suggests that Broca's area should mediate speech perception (e.g., Liberman & Mattingly 1985).

Recently we found one condition during speech perception that activates Broca's area. When listeners see a talker's facial movements along with hearing during speech production, Broca's area is active, but not when presented with the sound alone or the visual information alone. This is consistent with the idea that an observation/execution matching system (Rizzolatti & Arbib 1998) takes visual information about production in during comprehension to support a sensory-attentional contingency. Knowledge about speech production in Broca's area is active only when there is direct sensory (visual) evidence about motor movements from the talker.

Thus, listeners may recruit relevant sensory-attentional contingencies during perception. These data also suggest a methodological concern. There is a tendency to treat speech comprehension from a reductionist perspective. Research often examines phoneme and word perception in isolation from the natural context. If sensory-attentional contingencies are important we must study perception in contexts that provide for the use of these contingencies. Speech perception should be studied in richer, naturalistic settings such as face-to-face communication, since this is the environment that shaped the evolution of communication and is the context of daily use.

Finally, the change from sensory-motor to sensory-attentional contingencies has an implication for understanding vision. The motor behavior underlying sensorimotor contingencies is a physical manifestation of attentional exploration. Perhaps it is the attentional shift, not the motor activity, that is the basis for these contingencies. Observers can shift attention within the visual field even without eye movements (e.g., Posner et al. 1980). Attention shifts may provide the same kinds of contingencies that are postulated to govern motor-based visual exploration. Perhaps, perception in all sensory modalities is better explained by appealing to knowledge of sensory-attentional contingencies.

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The explanatory gap is still there

Klaus Oberauer

University of Potsdam, Allgemeine Psychologie I, 14415 Potsdam, Germany. **ko@rz.uni-potsdam.de**
http://www.psych.uni-potsdam.de/people/oberauer/index-d.html

Abstract: I argue that O'Regan & Noë's (O&N's) theory is in a no better position than any other theory to solve the "hard problem" of consciousness. Getting rid of the explanatory gap by exchanging sensorimotor contingencies for neural representations is an illusion.

Sometimes a good idea must be advanced by advertising it with bold claims. Sometimes this seduces authors into pushing a theory beyond the limits of what it can accomplish. I think that **O'Regan's & Noë**'s (**O&N**'s) account offers many intriguing ideas about how the visual system works, but it does not help to solve the philosophical problems surrounding conscious experience.

The so-called "hard problem" of consciousness (Chalmers 1996a) is how to explain the fact that "there is something that it is like to have an experience" (target article, sect. 6.3). Targeting competing views, **O&N** express this problem very clearly as the "fundamental question of how a neural code could ever give rise to experience at all" (sect. 1.2). Does this rhetorical question lose any of its force when we replace "neural code" with "currently exercised sensorimotor contingencies"? O&N argue that their approach turns the hard problem of consciousness into a non-problem. I think their argument is flawed.

O&N's first step is to recast the problem into the question: What are qualia?, which they go on to characterize as "properties of experiential states or events" (sect. 6.3). Experiences, they argue, are not states but "ways of acting, . . . things we do." These are not states, but they certainly are events. So it seems completely reasonable to characterize qualia as features of the events going on during perceptual activity. It is true that qualia are often linked to representational states; this is because representational states play a key role in most theories of cognition. This does not imply that when one drops the concept of a static representation, the concept of qualia becomes meaningless. "Qualia" is a descriptive term that captures the fact that we experience something while we perceive, and that this experience has a certain quality that could be different for different people even if we perceived (in an information-processing sense) the same thing. For example, one could imagine that the same representation – or the same executed sensorimotor contingency – that is associated with the experience of red in one person gives rise to the experience of green in another person, and vice versa (cf. Palmer 1999a).

The second step is to analyze the qualitative character of an experience, even one as simple as the perception of a red wall, as something complex, consisting of the knowledge of "changes in the incoming information" contingent on the perceiver's activity. But what about the information that changes – is it experienced? Is the change (or that which is changed) something we experience? If yes, the question is just shifted down from the complex experience of "red" to the experience of the incoming information. If no, the fundamental question arises how registering not-experienced changes of incoming information in a brain generates experience. That is, why is it like something when my brain registers changes on my retina, and why is the experience one of red? The same pattern of changes in the information influx could as well "feel" green. Borrowing from **O&N**'s introduction (sect. 1.2): What is the mapping function from a complex structure of sensorimotor contingencies onto the experience of one color or another?

It seems to be important to **O&N** that "there is no simple, unanalyzable core of the experience" (sect. 6.4). If this is so, it only follows that there are no simple, unanalyzable qualia; qualia are complex entities. It does not follow that qualia don't exist (even if there are philosophers who characterize qualia as simple). We are still left with the problem of explaining how elements that have no experiential quality can give rise to an experience when put together.

O&N seem to suggest that all there is to the quality of an experience is the structure of the sensorimotor contingencies – experiences differ because they are based on the execution of different sensorimotor contingencies. These contingencies, the knowledge about them, and their execution are part of the functional properties of our brains. The "explanatory gap" arises because all these information-processing activities could work as well without us experiencing anything at all. If sensorimotor contingencies are to explain conscious experience, the existence of conscious experience should follow with logical necessity from the existence of the appropriate sensorimotor contingencies (together with the necessary boundary conditions, for example, a world in which they can be executed, cf. Chalmers 1996a). To illustrate: We could build the appropriate sensorimotor contingencies into a robot (e.g., one that can drive a Porsche, among other things), and this should allow us to deduce that the machine has a rich inner life (e.g., is able to feel what it is like to drive a Porsche). I'd rather stay agnostic on this, even for a very graceful robot.

It seems that **O&N** would be more confident. In their discussion of blindsight (sect. 7.2) they define experience in terms of being able to describe and react appropriately to what one sees. This is a common materialist reply to the hard problem: The denial of phenomenal experience as an explanandum – everything that needs explaining is behaviour (Dennett 1991). In this case it all comes down to the empirical question, which theory is better suited to explain the observed behavior. Then, however, there is no room for the "fundamental question" raised in the introduction: How does anything going on in our brains and their causal interactions with the world give rise to experience? With regard to this question, the approach of O&N does not achieve more than any other theory of vision: It simply evades it.

Sins of omission and commission

Gerard O'Brien and Jon Opie

Department of Philosophy, University of Adelaide, Adelaide, South Australia 5005. **gerard.obrien@adelaide.edu.au** **jon.opie@adelaide.edu.au**
http://www.arts.adelaide.edu.au/Philosophy/gobrien.htm
http://www.arts.adelaide.edu.au/Philosophy/jopie.htm

Abstract: O'Regan & Noë (O&N) fail to address adequately the two most historically important reasons for seeking to explain visual experience in terms of internal representations. They are silent about the apparently inferential nature of perception, and mistaken about the significance of the phenomenology accompanying dreams, hallucinations, and mental imagery.

Despite the plethora of theories that have surfaced over the years, there are really only two ways of explaining visual experience. The first accords with the commonsense intuition that when we open our eyes and look around, we have direct access to the world. In this view, visual experience supervenes on the interaction between our visual apparatus and the visually detectable properties of the environment. The second approach rejects commonsense, and holds that our perceptual access to the world is always indirect. What we see is not the actual world; what we see (or, better, what we see *with*) are mental representations constructed by our brains. According to this "constructivist" conception, visual experience supervenes on the brain alone.

Although the history of vision science has seen many oscillations between these two poles, constructivism currently dominates the discipline. **O'Regan & Noë**'s (**O&N**'s) sensorimotor account of vision, on the other hand, favours commonsense over mainstream thinking. The great drawback with constructivist theories of vision, they observe, is that such theories are burdened with the problem of explaining how neural representations give rise to visual experiences – a problem that has stubbornly resisted all attempts at resolution. By contrast, their sensorimotor account, precisely because it rejects the idea that the brain constructs visual experiences, steps right over this explanatory gap. Visual experiences occur when our visual apparatus, replete with the structure of its sensorimotor contingencies, actively engages with the world. Such experiences are not states in the head, they are "ways of acting" (sect. 6.3).

O&N are right about the extra explanatory burden that is carried by constructivist theories of perception. And they are no doubt right to be dissatisfied with current attempts to explain the qualitative character of visual experience in representational terms. Nonetheless, before abandoning constructivism it would be wise to consider why, for nearly thirty years now, vision scientists have almost universally adopted this counter-intuitive approach. The reasons are numerous, but two deserve special mention because of their historical significance.

First, our perceptual responses are underdetermined by the information our visual apparatus garners from its interaction with the world. The conclusion many theorists find inescapable is that, appearances to the contrary notwithstanding, visual perception must be an inferential process – one that constructs representations of the environment by combining stimulus data with information internal to the perceiver. (This form of argument is too familiar to require detailed rehearsal here. For a classic rendering see Fodor and Pylyshyn 1981, and for a more recent statement see Palmer 1999b, p. 55. Palmer notes that the structure of the environment cannot be unambiguously determined by stimulus data, even if we factor in the dynamics of organism-environment coupling, because "time is also a dimension of the environment.")

Second, there are several kinds of visual experience which occur when organism and environment are not actively coupled. The standard examples are the visual experiences that accompany dreams, hallucinations, and mental imagery. Such experiences provide compelling evidence that neural activity is sometimes sufficient for visual awareness. Furthermore, many theorists think it reasonable to surmise that dreams and hallucinations indicate something important about the nature of visual experience more generally, namely, that even "veridical" experiences are constructed by the brain, and thus implicate internal representations.

O&N are silent about the first of these reasons for preferring constructivism, a serious omission given the fundamental role this form of argument has played in shaping cognitive science. They do, however, address dreams and mental imagery, albeit briefly (sect. 4.4). According to O&N, the worry is that "since dreams and mental images are apparently pictorial in nature, this seems to show that we *are,* after all, capable of creating an internal iconic image." But this, they think, is as misguided "as the supposition that to see red, there must be red neurons in the brain," and conclude that "the supposed fact that things appear pictorial to us in no way requires there to be pictures in the head."

O&N's response here is lame, because they misconstrue the problem that dreams, hallucinations, and mental imagery pose for their account. These mental phenomena are problematic *not* because they seem to depend on internal *icons;* they are problematic because they can occur in the absence of any interaction between the visual apparatus and the world. The precise form of visual representations – whether, for example, they are more like pictures or linguistic tokens – is indeed a much debated issue (see Block 1981). But this is a debate *within* the constructivist camp, not between advocates of constructivism and their critics. What O&N must demonstrate is that they can account for the phenomenology associated with dreams, hallucinations, and mental imagery without postulating internal representations *of any kind.* At the very least they must explain how visual experiences can arise in situations where the very activity that is supposed to account for experience is missing.

To sum up: **O&N** are guilty of two sins, one of omission and one of commission. They are *silent* about the apparently inferential nature of perception, and *mistaken* about the problem that dreams, hallucinations, and mental imagery create for their sensorimotor account of vision. Since O&N fail to address adequately the two most important arguments for constructivism, it is reasonable to conclude that the challenge for visual science remains that of explaining how neural representations give rise to visual experiences.

Perceptual theories that emphasize action are necessary but not sufficient

John R. Pani

Department of Psychological and Brain Sciences, University of Louisville, Louisville, KY 40292. **jrpani@louisville.edu**
http://www.louisville.edu/~jrpani01

Abstract: Theories that make action central to perception are plausible, though largely untried, for space perception. However, explaining object recognition, and high-level perception generally, will require reference to representations of the world in some form. Nonetheless, action is central to cognition, and explaining high-level perception will be aided by integrating an understanding of action with other aspects of perception.

Theoretical advances in psychology nearly always follow new empirical demonstrations. If the sensorimotor theory of perception proves to be an advance, it will be because it provides a successful account of the phenomena of change blindness. On this point, it seems to me that where the theory concerns space perception, it has much to recommend it. Change blindness, however, appears relevant also to object and scene recognition (e.g., Archambault et al. 1999; Hollingworth & Henderson 2000; Pani 2000), and here the sensorimotor theory seems to be on uncertain ground. Nonetheless, it is important to develop theories in which the possibilities for action are embedded in our understanding and use of concepts.

Low-level perception. O'Regan & Noë (**O&N**) suggest that perception consists largely of mastering sensorimotor contingencies through a variety of different forms of action. This conception reinforces a number of important statements about perception. One of these is J. J. Gibson's (e.g., 1979/1986) argument that perception does not include static percepts, such as a percept of the shape of an object. Instead, perception involves tuning the sensory systems to sets of relations and transformations that occur continuously, often due to observer action or locomotion. The individual becomes attuned to the information that specifies an object of constant shape, and static percepts of shape are unnecessary. In extending this view to higher perceptual and cognitive functions, Neisser (e.g., 1976) argued that the anticipation of perceptual information within systems of action was the essential ingredient for bridging perception and cognition.

The authors add two elements to this account. First, the world serves as an outside memory for action. Second, our perception of the world is not a reflection of the content of mental representations, but rather, is due to the structure of the world itself and our ability to act intelligently with respect to it. That is, perceptual knowledge exists only in sensorimotor action.

To account for change blindness, the authors discount the notion that untutored intuitions about the richness of momentary perceptions are a sound basis for theory. They suggest that each moment of perception includes relatively sparse information, and that it is through the combined efforts of well-adapted actions that the richness of perception is constituted. Successful action is successful perception, and no representation of the world is necessary.

For perception of geometric properties of the world, this seems a reasonable approach, but significant theoretical challenges remain. People not only perceive and act in a complex world, they understand that they do, as evidenced by their concepts, language, and behavior. For example, we understand that innumerable saccades and shifts of attention extended across time and space all sample information from one scene. How do we know this (see Neisser 1976)? The more severe we are in saying that there is no information outside of the focus of attention, and the more severe we are in rejecting the contribution of mental representations (e.g., in working memory), the more challenging these issues become. It will be nontrivial to work out the details of such an account, and it may be necessary to allow more information into momentary perceptions and working memory. To revive a debate that took place with regard to auditory attention (e.g., Norman 1969), change blindness may be due in part to limitations on memory (see Hollingworth 2001; Pani 2000; Simons 2000b).

High-level perception. It was a truism insisted upon by the behaviorists years ago that knowledge is expressed in behavior. No sensible cognitive theory ultimately isolates its components from the necessity to generate actions, and theories about action are not necessarily theories without representations.

At the same time, no theory of human perception (as a whole) can avoid the fact that perception includes object recognition, and that recognition involves categorization. Categories are pivot-points that determine choices between potentially large sets of diverse actions, and they affect action at every level from eye movements on upward (see Lichtenstein & Brewer 1980). The broad shift of behavior that comes from realizing, for example, that a store is closed or that an animal is stuffed demonstrates that the individual *knows what these facts mean.* And the stored information about what something means can be considered to be a representation, whether or not the function of that information is to generate behavior. Even if a theory of object recognition is devoted to explaining human action, claiming that the theory has no representations may be little more than an aesthetic decision regarding labels.

Categories, thinking, and concepts. Having expressed some skepticism about the stronger claims of the sensorimotor theory, I would like also to express some enthusiasm about the enterprise. As theories of concepts based on the possibilities of action are developed, new sets of explanations become possible. Some cognitive phenomena will be associated particularly closely with this type of explanation. For example, people's typical indifference to how well mental images depict information probably is due to the fact that the images are part of a larger effort for which pictorial fidelity of any single image is unnecessary to the outcome (see Pani 1996). Similarly, the time-honored problem of the consciousness of meanings (as opposed to sensations and images) probably will have to be explained as an instance of a complex state of preparation within sets of possible actions (Brown 1958; Humphrey 1951; Pani 1996). For example, try a bit of introspection. Answer the question: Can a man marry his widow's sister? As you came to your answer, what was the nature of the conscious event? I suspect that describing the experience as a changed set of anticipations with respect to possible actions related to the man in question (e.g., whether to introduce yourself) is much more promising than a description that refers to images or internal speech.

Seeing, acting, and knowing

Zenon W. Pylyshyn

Center for Cognitive Science, Rutgers University, New Brunswick, NJ 08854-8020. **zenon@ruccs.rutgers.edu**
http://ruccs.rutgers.edu/faculty/pylyshyn.html

Abstract: The target article proposes that visual experience arises when sensorimotor contingencies are exploited in perception. This novel analysis of visual experience fares no better than the other proposals that the article rightly dismisses, and for the same reasons. Extracting invariants may be needed for recognition, but it is neither necessary nor sufficient for having a visual experience. While the idea that vision involves the active extraction of sensorimotor invariants has merit, it does not replace the need for perceptual representations. Vision is not just for the immediate controlling of action; it is also for finding out about the world, from which inferences may be drawn and beliefs changed.

This target article by **O'Regan & Noë** (**O&N**) presents a radically different analysis of the nature of perceptual experience. In view of the intransigence of the problem, a radical proposal is the only kind worth considering. The article builds upon two currently popular ideas about vision: the idea that visual perception is active and the idea that our intuitions mislead us about what is in our head when we see. The thesis shares with J. J. Gibson the belief that seeing consists in actively extracting invariants from the world, though in the present proposal these invariants are defined over the manifold of sensory-motor contingencies. While the article presents a welcome admonition against certain common misconceptions about vision, it has some drawbacks of its own as an account of the nature of *visual experience.*

Any claim of the form "visual experience consists of X" immediately raises a family of familiar problems, regardless of whether X is "having a mental picture" or "extracting the invariant sensory-motor contingencies." Ironically, the kind of problem such claims raise is explained with particular clarity in section 1 of the target article: All such claims fail to specify why X leads to *that* experience, or indeed why it should lead to *any* experience. Nothing in the current proposal takes it out of this explanatory dead end. Sensorimotor contingencies can no more explain the qualitative differences between modalities, than can the much simpler hypothesis that different modalities arise from the activation of different sense organs, or different efferent fibers, or different parts of the cortex. These may all distinguish among modalities, yet none – including the present proposal – addresses the question of why they are associated with different experiences; why they *feel* different.

If the experience of seeing arises from the extraction of the same sorts of sensorimotor invariants that must be extracted in object recognition, then one might expect that people who achieve a high level of proficiency in object recognition might have similar visual experiences. Yet blind people can reach very high levels of proficiency in object recognition, without any accompanying visual experience. There is no reason to believe that the experience of seeing can arise from anything other than direct stimulation of the visual system. In contrast, one *can* get genuine visual experiences without extracting sensorimotor invariants, providing that the inputs actually stimulate the visual nervous system. Such results are consistent with Müller's doctrine of specific nerve energies (see, e.g., Müller 1896), but are not consistent with the view that experience "is constituted by the character of the sensorimotor contingencies at play when we perceive" (target article, sect. 6.3).

The discussion of visual awareness can be factored from the main body of the target article, which is about what vision does, or to put it in David Marr's terms, what function it computes. Here, the authors make an interesting argument for including the activity of the motor system as part of vision. Yet one thing that can be said in favor of the old fashioned approach to vision is that it has achieved some remarkable results in the past 30 years. In the tradition often associated with David Marr and others, these invariants take a form called "natural constraints," which are typically subject to rigorous mathematical analyses. This approach takes into account possible alternative viewpoints, which is why "nonaccidental properties" play a major role. Yet it does not include any analysis of concurrent activities of the motor system. When similar success has been achieved in characterizing recognition in terms of sensorimotor contingencies, the authors would be justified in claiming a breakthrough in the analysis of vision.

O&N devote considerable space to criticizing the appeal to "mental pictures" in vision, and I could not agree more with them. But then they play down the idea that vision involves anything that might be called a representation, choosing, instead to emphasize "the world as external memory." While this is an important idea which I have also championed (Pylyshyn 2001), it does not obviate the need for some form of visual representation. Neither does recognizing the importance of vision for guiding action. Milner and Goodale (1995) have proposed that vision has evolved largely for controlling actions rather than creating internal representations. This idea led Milner and Goodale to investigate many properties of the visual system that heretofore had been neglected; such as that visual information may be available for motor control but not available for conscious access, suggesting that there may be more than one "visual system." While O&N embrace the vision-for-action principle, they somewhat surprisingly (and unnecessarily) retain the idea that vision results in a unitary conscious experience.

While it is true that we often use our visual system to determine our actions, we also use it to find out what is in the world simply because we *want to know.* As George Miller once put it, we are basically *informavores:* we seek to know even if we have no possibility of acting towards what we see – as we do when we watch television or visit an art gallery or read a book. *Most* things we see are things we cannot act upon directly, such as the words in the target article. Of course what we find out through vision may lead to new beliefs and so may eventually affect what we do, but this is not the sort of behavior people have in mind when they speak of visually guided action (writing a commentary on an article is not an example of a visually guided action!). Much of what we see guides our action only indirectly by changing what we believe and perhaps what we want.

The target article also emphasizes the role of visual exploration. Yet the fact that we *can* clearly see things we have not visually explored, or have only explored in a passive way, as in the Zollner-Parks "eye of the needle" and other successive-presentation phenomena, tells us that sensorimotor contingencies are not necessary for vision, even though they may often play a role. The usual way to deal with this dilemma, which the authors have not taken, is to appeal to ecological validity . Such lines of evidence as are reviewed in the target article do suggest that vision and action may be more closely linked than many believed; but they are far from showing that our visual system is designed around sensorimotor contingencies and knows nothing of the world it sees.

Neural correlates of consciousness are not pictorial representations

Geraint Rees[a] and Chris Frith[b]

[a]*Institute of Cognitive Neuroscience, University College London, London WC1N 3AR, United Kingdom;* [b]*Wellcome Department of Cognitive Neurology, University College London, London WC1N 3BG, United Kingdom.*
g.rees@fil.ion.ucl.ac.uk **http://www.fil.ion.ucl.ac.uk/~grees**
c.frith@fil.ion.ucl.ac.uk **http://www.fil.ion.ucl.ac.uk/principals.html**

Abstract: O'Regan & Noë (O&N) are pessimistic about the prospects for discovering the neural correlates of consciousness. They argue that there can be no one-to-one correspondence between awareness and patterns of neural activity in the brain, so a project attempting to identify the neural correlates of consciousness is doomed to failure. We believe that this degree of pessimism may be overstated; recent empirical data show some convergence in describing consistent patterns of neural activity associated with visual consciousness.

A consistent finding in humans and monkeys is that damage to functionally specialized regions of the visual cortex leads to deficient awareness of the visual attribute represented in that area, without impairment of awareness for other attributes. For example, damage to the human homologue of V5/MT (middle temporal area) leads to akinetopsia (Zihl et al. 1983). Alteration of activity in that area through microstimulation (Salzman et al. 1990) or transcranial magnetic stimulation (Beckers & Homberg 1992; though see Pascual-Leone & Walsh 2001) leads to altered perception of that attribute. Even when sensory input and motor output are held constant, changes in perceptual awareness (Tong et al. 1998) or hallucinations (ffytche et al. 1998; Silbersweig et al. 1995) are associated with enhanced activity in areas of visual cortex with functional specializations that correspond to the percept experienced. These remarkably consistent results from a wide variety of experimental techniques suggest that activity in functionally specialized areas of visual cortex is correlated with, and necessary for, visual awareness.

We do not claim that this neural correlate of consciousness is constitutive of, or even sufficient for, visual awareness; merely that it represents a consistent (and probably necessary) correlate of consciousness. Recent neuroimaging experiments suggest that visual cortex activity can be detected for unseen stimuli in parietal extinction (Rees et al. 2000; Vuilleumier et al. 2001), during change blindness (Beck et al. 2001) or following pattern masking (Dehaene et al. 2001). When stimuli reach awareness, not only is enhanced activity observed in the ventral visual pathway, but also in areas of frontal and parietal cortex (Kleinschmidt et al. 1998; Lumer 2000). For the parietal cortex in particular, a remarkably consistent locus of activation correlated with awareness is seen in the superior parietal lobule (Rees 2001). Parietal and prefrontal cortices are often associated with attention and motor control, so the consistent involvement of areas associated with action in conscious awareness is supportive of the general notion of a close relationship between (conscious) perception and action. However, activity in these areas is correlated with awareness even when sensory stimulation and motor behavior is held constant (Frith et al. 1999).

A consistent association of parietal and prefrontal activity with visual awareness supports the notion that motor control systems may play an important role in visual awareness, as **O'Regan & Noë** (**O&N**) suggest. However, it also implies that involvement of these systems can be independent of overt behavior (and consequent changes in the environment). Thus, an important qualification for their theoretical claims is that "mastery of sensorimotor contingencies" may reflect covert rather than overt behavior. The challenge for O&N is therefore to specify how this covert "mastery of sensorimotor contingency" differs from other cognitive processes such as attention or working memory. Indeed, the notion that motor activity is not necessary for awareness is consistent with clinical observations. Damage to motor cortex leading to paralysis causes little or no change in conscious experience, either acutely or in the long term. Indeed, an individual almost completely paralysed (apart from the ability to blink) authored a best-selling volume of short stories, displaying apparently normal consciousness (Bauby 1997). This failure to identify changes in conscious experience following changes in the ability of individuals to master sensorimotor contingencies must place important constraints on O&N's theoretical approach.

The notion of the neural correlates of visual consciousness as reflected in activity in a distributed network of cortical areas is rather different to **O&N**'s characterization of such research as searching for a pictorial representation of the outside world inside the brain. No such representation is either assumed or implied by the research we review here. However, the consistent activation of specific areas poses a challenge to O&N's predictions that no one-to-one correspondence between attributes represented in consciousness and brain activity is possible. We are sympathetic to the notion that consideration of action may have an important role to play in explaining how activity in the brain is associated with consciousness (Neisser 1967). However, empirical data does not support the wider implications of O&N's claim that the study of the neural correlates of consciousness is doomed to inconsistency and failure.

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Dreaming and the place of consciousness in nature

Antti Revonsuo

Department of Philosophy, Center for Cognitive Neuroscience, University of Turku, FIN-20014 Turku, Finland. **revonsuo@utu.fi**

Abstract: The research program defended by O'Regan & Noë (O&N) cannot give any plausible explanation for the fact that during REM-sleep the brain regularly generates subjective experiences (dreams) where visual phenomenology is especially prominent. This internal experience is almost invariably organized in the form of "being-in-the-world." Dreaming presents a serious unaccountable anomaly for the sensorimotor research program and reveals that some of its fundamental assumptions about the nature of consciousness are questionable.

O'Regan & Noë (**O&N**) propose a new research program on vision and consciousness that combines the behavioristic tradition of Ryle and Dennett with modern views of "embodied" cognition. Among the core assumptions of this program are the following: Vision (and subjective visual consciousness) is a phenomenon realized at the level of organism-environment interaction; it is not to be found at any lower (subpersonal) levels of organization. Neither the brain in isolation from its environment nor any particular part or process or activity within the brain is sufficient for visual consciousness. This account is in accordance with phenomenology, for seeing is directed to the world and in seeing we are aware of being embedded in the centre of a visual environment, not of pictorial representations located within our heads; nor are qualia or binding required, for there is nothing phenomenally qualitative or unified in the brain.

The competing view is described as implying that visual consciousness is a unified pictorial representation within the head which, when activated, produces qualitative experiences. This research program tries to discover the direct neural correlates of consciousness in the brain. However, even if found, they would not explain how consciousness is produced. Furthermore, this view may imply the postulation of a homunculus who looks at the internal representations.

In my view, both of these research programs have got something right, but neither of them is entirely acceptable. **O&N** are correct in that our phenomenology is indeed experience of "being-in-the-world" rather than "pictures-in-the-head." But what they do not realize is that the brain might be entirely sufficient for producing experiences in the form of "being-in-the-world"! Incontestable evidence from dream research (e.g., Foulkes 1985; Strauch & Meier 1996) shows that by far the most prominent form of dream experience is "being-in-the-world": the dreamer finds herself embodied in a body-image embedded in the center of an organized, temporally progressing perceptual world consisting of the full range of sensory experiences in all modalities, visual experiences being the most prominent. Thus, the form of dream experience is identical to that of waking experience. Dreams are never experienced as "pictures-in-the-head."

But now we should ask: If dreaming is an instantiation of subjective experience (consciousness), where is this phenomenon (or where are the conditions sufficient for bringing it about) located in the physical world (Revonsuo 1998)? During REM sleep, organism-environment interaction is virtually impossible because of the "sensory input blockade" that keeps sensory stimulation from modulating the content of consciousness and the "motor output blockade" that produces nearly complete muscle atonia. At the same time, the brain is internally activated virtually to the same extent as during wakefulness (Hobson 1988; Jouvet 1999). Now, by any logic I am aware of, it necessarily follows from this evidence that the immediate causal conditions sufficient for bringing about the full range of subjective conscious experiences must reside inside the brain. Realistic experiences of "being-in-the-world" require nothing more than a brain that is physiologically in REM sleep.

These empirical facts are sufficient to disconfirm the claim by **O&N** that (visual) conscious experience in principle could not reside at the subpersonal levels of organization. O&N briefly discuss dreams, but they provide no description of the facts revealed by dream research about the phenomenological content of dream experience, nor any mention of the neurophysiological mechanisms directly responsible for bringing dreams about. That is not surprising, for most of those facts would be difficult to incorporate into their account of consciousness. For example, adventitiously blind people who nevermore can engage in any visual exploration of their environment nevertheless every once in a while enjoy fully visual dreams (i.e., experiences of being embedded in a visual environment). Such dreams are of special significance for them, because dreaming is the only occasion that remains for them to enjoy the visual qualitative experience of colors or the actual sight of the face of a loved one (Rainville 1994).

If **O&N**'s account cannot incorporate dreams in any plausible manner, what kind of avenues are then left for somebody who takes them seriously? The only alternative is not, as O&N seem to fear, the resort to the view that there are pictures in the head and homunculi looking at them. Instead, the starting point ought to be that, both during dreaming and during wakefulness, consciousness manifests itself in the form of "being-in-the-world" – experiences which are brought about in the brain. Consciousness can be thought of as a real biological phenomenon in the brain, and like other such phenomena, it resides at a specific level in the hierarchical system of ontological levels of biological organization. A reasonable empirical working hypothesis is that consciousness, or the "phenomenal" level, is one of the higher levels of neural or electrophysiological organization that still remain to be discovered in the brain (Revonsuo 2000).

I agree that finding the neural *correlates* of consciousness will not suffice, for correlation is not an explanatory relationship. Biological explanation instead seeks for the lower-level constitutive mechanisms. Thus, the lower levels of organization that figure in the explanation of consciousness not only correlate with consciousness but constitute it, and the features of the lower level must bear intelligible explanatory relationships to features at the higher phenomenal level (isomorphism may be one such relationship, but certainly not the only one; Revonsuo 2001). **O&N** seem to claim precognitive knowledge about the future course of neuroscience, since they are absolutely convinced that no explanatory relationships between consciousness and any phenomenon in the brain will ever be found. But that is just an argument from ignorance. Self-replication of biological organisms was an awesome mystery until it was solved by showing how the lower-level constitutive biological mechanisms can explain it. Similarly, if consciousness is a real biological phenomenon in the brain, we simply have to apply the strategies of biological explanation to this phenomenon in order to get a clearer picture of what its explanation might imply.

In conclusion, I submit that **O&N** have not bridged the explanatory gap. They have merely decided to pretend (along with Dennett) that, from the third-person's point of view, there is nothing out there on the other side of the gap, so no attempts to bridge it are necessary. Neither this nor any other commentary is likely to change their philosophical views in any detectable way, but anybody who has not yet made up his mind about which research program on consciousness is to be favoured should perhaps think twice whether or not O&N's philosophical approach is true to the empirical facts about the place of subjective consciousness in nature.

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The sensorimotor contingency of multisensory localization correlates with the conscious percept of spatial unity

Gwendolyn E. Roberson,[a] Mark T. Wallace,[b] and James A. Schirillo[a]

[a]*Department of Psychology, Wake Forest University, Winston-Salem, NC 27109;* [b]*Department of Neurobiology & Anatomy, Wake Forest University School of Medicine, Winston-Salem, NC 27151.* **robege0@wfu.edu mwallace@wfubmc.edu schirija@wfu.edu**

Abstract: Two cross-modal experiments provide partial support for O'Regan & Noë's (O&N's) claim that sensorimotor contingencies mediate perception. Differences in locating a target sound accompanied by a spatially disparate neutral light correlate with whether the two stimuli were perceived as spatially unified. This correlation suggests that internal representations are necessary for conscious perception, which may also mediate sensorimotor contingencies.

O'Regan & Noë (**O&N**) call upon the scientific community "to develop modes of first-person investigation of experience that do not suffer from the flaws of qualia based (introspectionist) approaches" (sect. 7.3, para. 7). Our work on cross-modal processing has employed such methods, obtaining results both in keeping with and at odds with the authors' basic tenets.

Our experiments have examined a form of the ventriloquism illusion, in which the location of a target sound can be made to appear as originating from the location of a spatially disparate neutral visual signal. Using this approach we have found evidence of what we believe to be correlates of both sensorimotor contingencies and conscious perception that demonstrates a striking interrelationship between these measures.

In our paradigm we presented a 50 msec neutral visual stimulus (i.e., an LED) 200–800 msec after the onset of a 50 msec auditory target (i.e., broadband noise burst). The target sound was presented at a range of locations from 0º to 30º from the midline, while the LED was presented at a range of spatial disparities (i.e., 0º to 15º) from this target. Subjects used a laser pointer to indicate the perceived location of the target sound, and a foot pedal to report whether the light-sound pairings appeared spatially "unified" (i.e., originating from the same location).

Localization performance, a measure we posit to reveal sensorimotor contingency, was found to be strongly correlated with whether subjects perceived the two stimuli as spatially unified, a report we posit to reflect conscious perception. Thus, independent of spatial disparity, when perceptual unity was reported, localization bias approximated 100%. That is, subjects pointed at the light, a result analogous to visual capture (Fig. 1). Conversely, when subjects reported perceptual non-unity, bias was near 0% for large disparities. Interestingly, when spatial non-unity was reported at smaller disparities, bias was actually *negative,* in that the target sound was localized in the direction *away* from the light. That is, subjects localized the sound *further* away from the light with small disparities when the stimuli were perceived as spatially distinct.

We take this relationship between the reporting of spatial unity and localization performance to be supportive of **O&N**'s assertion that "*perception can now be understood as the activity of exploring the environment in ways mediated by knowledge of the relevant sensorimotor contingencies*" (sect. 2.5, emphasis in original). In essence, we have demonstrated that the pattern of localization bias a light has upon a target sound results from their dynamic sensorimotor contingencies, which coincide with whether the signals

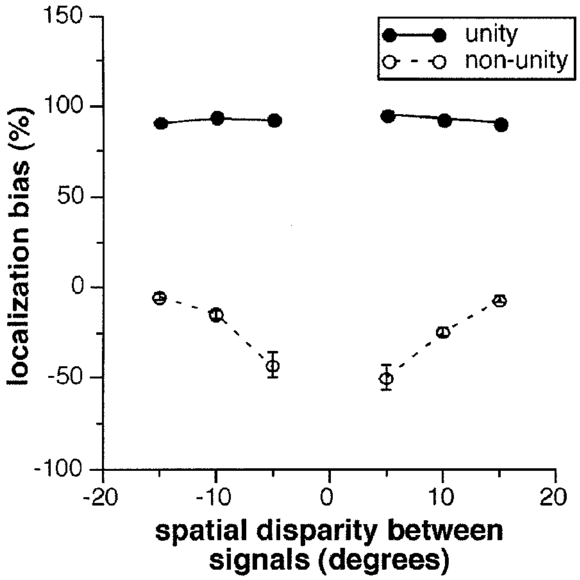

Figure 1 (Roberson et al.). Localization bias plotted as a function of the spatial disparity between the visual and auditory signals when subjects judged the signals to be spatially unified (unity) or not unified (non-unity). Error bars represents SEM.

are consciously represented as unified. Most striking is the finding that when the stimuli are spatially united in the *external world* (i.e., zero spatial disparity), they can still be reported as either unified or not, and this report is strongly correlated with localization performance. Furthermore, we agree, and feel that our data lends credence to O&N's claim that their theory allows for the ventriloquism effect by letting each modality "have their own specificities due to the particularities of the sensors and sensorimotor contingencies involved," yet granting "interactions between the senses are to be expected when there are systematic correlations and common sensorimotor contingencies" (sect. 5.15, last para.).

However, we also believe our results cannot be explained exclusively on the basis of this form of external representation. The strong influence of the neutral visual stimulus presented shortly *after* the auditory target suggests the workings of an internal representation which weights the contributions from the different sensory channels and compares these with a conceptual representation of space.

Furthermore, although we agree with the authors that localization (bias) may constitute the orientation activity typically considered a function of an observer-centered dorsal stream, and that judging unity may be a function of the object-centered ventral stream (sect. 8.5), we disagree with their claim that there is no need to join streams of information to produce "binding," whether conceptually or temporally (sect. 8.3). Our finding of a strong linkage between localization bias and judgments of unity suggests an interrelationship between these two streams. In fact, growing evidence from anatomical, physiological, and functional imaging studies suggests much more connectivity between these streams than traditionally believed; a connectivity that could serve as the substrate for such binding processes.

Finally, O&N claim that "seeing is constituted by the brain's present attunement to the changes that would occur as a consequence of an action on the part of the perceiver." This suggests that localization occurs prior to unity judgments, and that, in fact, these motor actions drive our perceptual judgments. However, the results of our study, and our belief in an internal spatial representation, leave open the possibility of the converse. That is, the conscious perception of spatial unity (or non-unity) may ultimately dictate the type of sensorimotor contingencies employed to localize objects in space.

The existence of internal visual memory representations

Jennifer D. Ryan[a] and Neal J. Cohen[b]

[a]*Rotman Research Institute, Baycrest Centre for Geriatric Care, Toronto, Ontario M4C 5S7 Canada;* [b]*Beckman Institute, University of Illinois at Urbana-Champaign, Urbana, IL 61801.*
jryan@rotman-baycrest.on.ca ncohen@s.psych.uiuc.edu

Abstract: Although O'Regan & Noë (O&N) claim that the world may serve as the viewers' external visual memory, findings from the field of memory research have demonstrated the existence of internal visual representations. These representations are stored in the viewer's brain, contain information regarding visual objects and their relations, guide subsequent exploration of the visual world and promote change detection.

In arguing that the existence of mental representations cannot explain the experience of seeing or produce visual consciousness, **O'Regan & Noë** (**O&N**) dispense altogether with internal representations of the visual world. In their view, the visual world serves as its own external memory for the observer. Vision (or seeing) is a skill, and the information that must be represented by the brain to accomplish it constitutes knowledge (or "mastery") of the sensorimotor contingencies that govern skillful visual exploration.

Whether certain kinds of mental representations are necessary and sufficient to mediate the consciously aware and experiential aspects of vision is an issue that we leave to other discussants. This commentary focuses instead on evidence from the field of memory research, including our own work, that emphasizes the existence of internal visual representations and that documents the use of such representations by the viewer in exploration of the visual world. We argue that vision and visual exploration necessarily entail an interaction between information currently present in the external world and stored memory representations derived from previous samplings of the visual world, even without the viewer's conscious awareness.

Upon walking into one of the rooms in a building that we know well on campus, we can easily and quickly perceive the colors of the many objects in view, identify the objects and people in the room, determine whether it is an office or classroom or conference room, and note whether the event in that room is a seminar or thesis defense or office party. The ability to rapidly parse such situations has long been attributed to internal representations of experience, in the form of schemas or general knowledge structures, as shown in work dating back at least as far as Bartlett (1932). That such representations also shape the nature of visual exploration, as measured by eye movements, has been shown in work by Loftus and Mackworth (1978) and Parker (1978), who found increased viewing of the region in scenes in which the usual semantic relations were violated.

O&N cite as evidence against internal visual representations the results of Wolfe et al. (2000) on inattentional amnesia. In that work, subjects were presented with the same display repeatedly across trials, but were to search for a different target item on each trial. There was no speed-up in search, under these conditions, despite the many repetitions of the display. By contrast, there is an emerging literature that supports the idea that search does have memory (Peterson et al. 2001) and an enormous literature demonstrating that recent exposure to individual visual objects can modulate the speed and efficacy of subsequent processing of those items. Performance in reading words and in identifying visually presented objects is enhanced when the items are repeated. That these repetition priming, or perceptual priming, effects are due to visual representations is suggested by evidence that priming shows considerable modality- and form-specificity; the effects are largest when the perceptual features are maintained across viewings (Roediger 1990; Tulving & Schacter 1990). Moreover, such priming effects are tied to representations in the brain. Functional neuroimaging data indicate that perceptual priming for visual materials is associated specifically with changes in cortical visual processing regions (Schacter & Buckner 1998). Prior exposure also shapes the nature of subsequent visual exploration of those materials when presented again, as measured by eye movements. Our own work has shown that the pattern of viewing of faces (Althoff & Cohen 1999) and of scenes (Ryan et al. 2000) is altered upon repeated presentations. These effects can occur in the absence of conscious or explicit memory for the (previously presented) primed items.

Our work has shown that visual representations include information about relations among the constituent elements of scenes, and are used by viewers to guide further visual exploration (Ryan et al. 2000). Subjects saw a series of scenes and then subsequently saw either repeated versions or manipulated versions of the scenes involving some difference in the relations among scene elements. Increased viewing was directed to the changed region in manipulated scenes, most notably when subjects were *unaware* of any scene manipulation. Accordingly, relational information was maintained in visual representations and was used by observers to guide subsequent eye movement behavior, even in the absence of conscious awareness of the change.

Chun and Jiang's (1998) findings of contextual cuing, in which subjects were faster in finding a target in a repeated display of distracters compared to a new display, as long as the position of the target within the display remained constant, lead to similar conclusions. Viewers were apparently able to form representations containing information about the target object and its relations to the distracters in the display. Viewers were then able to use this relational information to guide further search behavior even in the absence of conscious awareness of the information.

Another empirical evidence cited by **O&N** as proof against internal representations of the visual world is the phenomenon of change blindness, in which viewers are surprisingly poor at reporting changes made to scenes on-line. However, our most recent work demonstrates eye movement evidence of change *detection* (Ryan & Cohen, submitted), emphasizing the presence of visual memory representations that are maintained on-line and used to guide subsequent viewing behavior. After viewing an initial scene, subjects saw it again immediately, either repeated in its original form or in a manipulated version. Subjects directed increased viewing to the very region of change in manipulated scenes, even within the first gaze to the region. Additionally, the overall pattern of viewing of manipulated scenes was altered compared to viewing of repeated scenes, even when subjects were unaware that a change had occurred. Similar findings have also been reported by Hollingworth et al. (in press).

Taken together, these findings indicate that internal memory representations of the visual world play a critical role in vision and visual exploration. Visual representations containing information about viewed objects and the relations among them are maintained in viewers' brains and used to compare with the currently presented visual display in order to guide exploratory eye movement behavior.

Reexamining visual cognition in human infants: On the necessity of representation

Matthew Schlesinger

Department of Psychology, Southern Illinois University, Carbondale, IL 62901. **matthews@siu.edu** **http://www.siu.edu/~matthew**

Abstract: The sensorimotor account of vision proposed by O'Regan & Noë (O&N) challenges the classical view of visual cognition as a process of mentally representing the world. Many infant cognition researchers would probably disagree. I describe the surprising ability of young infants to represent and reason about the physical world, and ask how this capacity can be explained in non-representational terms. As a first step toward answering this question, I suggest that recent models of embodied cognition may help illustrate a way of escaping the representational trap.

O'Regan & Noë (**O&N**) present a compelling account of visual cognition that trades in the popular myth of vision as recovery and reconstruction of the 3D world, for a leaner, meaner alternative. I enthusiastically endorse their thesis that much of "seeing the world" can be better understood as a process of recognizing how actions in the world (e.g., eye and head movements) systematically transform sensory data over time. The theory of sensorimotor contingency reaches well beyond the domain of perception and visual consciousness, raising many important questions for other areas of research. In particular, as a developmental psychologist I would like to focus my commentary on the implications of O&N's proposal for infant cognition research.

Infants mentally represent the world. Across a wide range of knowledge domains (e.g., number, objects, causality, classes), there is now unequivocal, or at least overwhelming support for the conclusion that young infants mentally represent the world (Baillargeon 1999; Meltzoff & Moore 1998; Spelke 1998; Wynn 1992; however, see also Bogartz et al. 2000; Haith 1998; Rivera et al. 1999). For example, young infants react with surprise (i.e., increased attention) when they see two dolls placed behind a screen and then only one doll revealed when the screen is removed (Wynn 1992). Infants are similarly surprised when they see a drawbridge appear to rotate through a space that was occupied a moment before by a solid box (but not if the box is shown to be made of sponge).

It is typically assumed in these studies that infants mentally reconstruct salient features of the physical environment, forming internal copies or models of the external world that not only persist over time, but also guide infants' perceptual information-gathering. Complimenting the representational account of infants' visual cognition are a number of recent computational models that illustrate how such representations might arise during early development (Mareschal et al. 1999; Munakata et al. 1997; Simon 1998).

Infants operate on their mental representations of the world. It may not only be the case that infants mentally represent the world, but that they also seem to use these representations as detailed physical models when data from the real world are temporarily unavailable (e.g., when an object is occluded). For example, infants react with surprise at the sight of a car that reappears after its path is obstructed by a large, occluded box (Baillargeon 1986). Such findings are used to conclude that infants use mental models to actively *reason* about the physical world, by forecasting or predicting the outcomes of occluded events.

The representational account of infant visual cognition creates a difficult challenge for **O&N**'s theory. Much of what they marshal as evidence for their proposal are data and thought experiments from the here-and-now, like exploring a bottle that is in one's hands. How might we explain an infant's putative ability to hold in mind both the existence and location of an occluded object, or more impressively, to recognize when that object should obstruct the movement of another occluded object, within the formal framework of sensorimotor contingencies? It is unclear how the idea of the "world as an external representation" could account for such impressive mental skills.

A first step toward escaping the representational trap. Can the sensorimotor account of visual cognition explain the apparent representational prowess of young infants? This is a difficult question, but one that I hope **O&N** can somehow answer. However, paralleling their approach are a number of researchers (e.g., Ballard et al. 1997; Nolfi & Parisi 1999; Scheier & Pfeifer 1995; Schlesinger & Parisi 2001) who (1) advocate the notion of embodied knowledge, and (2) have investigated a variety of practical tasks that would seem to require mental or symbolic representations, but that can in fact be solved by assuming that knowledge is body-based, situated, and encoded implicitly through temporally-extended actions.

As an example of this approach, I have developed an oculomotor control model that simulates the eye movements of an infant as it tracks moving objects (Schlesinger & Barto 1999; Schlesinger & Parisi 2001). Using a reinforcement-learning algorithm, the eye-movement model quickly learns to anticipate the reappearance of an occluded object. Perhaps more impressively, like the young infants in Baillargeon's (1986) study, the model also tracks the target appropriately when its path is blocked by a hidden obstacle. Note that these prospective behaviors are achieved with only a simple associative learning mechanism, and without assuming or building in the capacity for memory or prediction.

Obviously, this eye-movement model is just one small step toward trying to explain infants' visual cognition in non-representational terms. Nevertheless, the model suggests that we can know about and act in the world, indeed, even anticipate future states of the world, without having to explicitly reference a mental model or symbolic representation. In this sense, of course, an important point of agreement between my model and **O&N**'s more general theoretical account is that *visual cognition is activity.* It is unclear to me, however, how far such a theory can go toward explaining not only the (apparent) capacity for infants to represent the world in symbolic form, but also their capacity for using those putative representations to act, judge, or reason about the world in a prospective manner.

Summary. I have highlighted here the representational account of infant cognition. My challenge to **O&N** is to continue to expand and elaborate their theory in at least two directions. First, I hope that they can flesh out the sensorimotor account of vision in enough detail to provide a compelling alternative to the idea that knowledge acquisition is simply a process of copying external reality. Second, and more generally, I encourage both authors to raise their sights, and to begin thinking beyond the question of learning and, instead, toward the lifelong process of perceptual and cognitive development.

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Change blindness, Gibson, and the sensorimotor theory of vision

Brian J. Scholl[a] and Daniel J. Simons[b]

[a]*Department of Psychology, Yale University, New Haven, CT 06520-8205;*
[b]*Department of Psychology, Harvard University, Cambridge, MA 02138.*
Brian.Scholl@yale.edu dsimons@wjh.harvard.edu
http://pantheon.yale.edu/~bs265
http://www.wjh.harvard.edu/~viscog/lab/

Abstract: We suggest that the sensorimotor "theory" of vision is really an unstructured collection of separate ideas, and that much of the evidence cited in its favor at best supports only a subset of these ideas. As an example, we note that work on change blindness does not "vindicate" (or even speak to) much of the sensorimotor framework. Moreover, the ideas themselves are not always internally consistent. Finally, the proposed framework draws on ideas initially espoused by James Gibson, but does little to differentiate itself from those earlier views. For even part of this framework to become testable, it must specify which sources of evidence can support or contradict each of the component hypotheses.

On its surface, the "sensorimotor account of vision" by **O'Regan & Noë** (**O&N**) has an impressive scope: among many other things, it allegedly explains the nature of visual consciousness; how sensory modalities differ; how sensation differs from perception; how we perceive a stable world despite eye movements; why visual binding is unnecessary; and why hundreds of years of philosophical analysis of the problem of qualia can be dismissed as misguided.

How can so many phenomena fall under the explanatory scope of this single theory? One reason, we suggest, is that it is not so much a coherent theory as an unstructured collection of three interesting ideas: (1) vision is active and exploratory rather than passive; (2) knowledge of sensorimotor contingencies plays a central role in conscious vision; and (3) the visual system uses the world as an "outside memory." Although most researchers would accept the first idea, the latter two are more controversial. More importantly, these ideas are essentially unrelated: each can be selectively denied while maintaining the others.

The scope of these hypotheses and the many types of evidence alleged to support them creates a substantial problem: given that the theory is not a single, structured claim, it is unclear which of the ideas are supported by which types of evidence. The sensorimotor theory is treated by **O&N** as a coherent whole, and evidence consistent with some of the ideas is inappropriately taken to substantiate the theory in its entirety.

The role (or lack thereof) of change blindness in the sensorimotor theory. Here we focus on just one instance of this error, involving *change blindness* – the phenomenon wherein surprisingly large changes go unnoticed, even when observers are actively trying to find them (see Simons 2000a). The authors view change blindness as central to their theory: "the sensorimotor approach to vision . . . has provided the impetus for a series of surprising experiments on what has come to be known as change blindness. The robustness of these results in turn serves to vindicate the framework itself" (sect. 9). We suggest that both of these claims are mistaken, and that change blindness does not directly support the sensorimotor theory.

O&N suggest that change blindness was discovered as a direct consequence of the sensorimotor theory, or more precisely, the "world as an outside memory" claim. Although this idea did provide some of the theoretical motivation for recent work on such phenomena, the initial work on change blindness was not motivated by this issue at all. Most early work on change blindness derived from the study of visual integration and focused on the detection of changes during reading. For example, McConkie and Zola (1979) showed that observers often failed to notice when every letter on a screen changed case during a saccade. Other work on the failure to notice changes, both theoretical and empirical, similarly predated the current theory (e.g., Dennett 1991; Hochberg 1986; Phillips 1974; Stroud 1955).

The notion of using the world as an outside memory (e.g., Brooks 1991; O'Regan 1992; Stroud 1955) might explain why several forms of change blindness occur: we intuitively expect to detect such changes, perhaps on account of implicit beliefs about the capacity and fidelity of internal representations, or perhaps because of implicit expectations about the range of unusual or distinctive events that will draw our attention (e.g., Levin et al. 2000; Scholl et al., submitted). In any case, accurate change detection, when it does occur (in situations which do not induce change blindness) may be driven largely by motion transients which draw attention back to the world itself (e.g., Simons et al. 2000). Though the externalized memory hypothesis might predict change blindness, however, it is not clear that the sensorimotor hypothesis would. Sensorimotor contingencies require an internal memory from one instant to the next, because detecting contingencies depends on the ability to note how an environment changes in response to actions such as a "flick of the eyes." However, if the observer relied solely on the external world to provide their memory, then nothing would ever be seen to change across such flicks of the eyes (due to saccade-contingent change blindness). How, then, would observers learn what was stable and what was variable over time and across eye and head movements?

Thus, change blindness – including the flicker and mudsplash paradigms developed by Rensink, O'Regan, and colleagues – provides no direct support for **O&N**'s sensorimotor contingency idea. In fact, it does not even directly support the externalized memory idea. Change blindness is consistent with the idea that we lack internalized, detailed representations: in the absence of such internal representations, change blindness would occur. However, the existence of change blindness does not logically require the absence of a representation (see Simons 2000b). Representations are needed to detect change, but they could also be present in the face of change blindness. For example, observers might represent both the original and changed scene, but simply fail to compare them directly (Levin et al., in press; Scott-Brown et al. 2000; Simons 2000b; Simons et al., in press). The presence of change blindness allows no conclusive inferences about the presence or absence of internal representations. All it tells us is that if we have such representations, we do not spontaneously gain conscious access to the differences between them.

Even if we grant the idea of an externalized memory, however, we can simultaneously deny every other aspect of the theory – including the idea that knowledge of sensorimotor contingencies plays a substantive role in conscious vision. Change blindness provides little support for the externalized memory idea and provides even less for the framework as a whole. It is thus misleading to characterize change blindness as vindication for the overall framework. At best, one small (and dissociable) part of the theory is *consistent* with change blindness.

Are sensorimotor contingencies truly sensory? Do we really lack representations? The problems induced by the lack of integration among the central ideas in **O&N**'s framework are amplified by the fact that the individual ideas are not always internally consistent on their own. Take, for example, the central idea that perception derives from knowledge of sensorimotor contingencies. This claim depends on a consistent relationship between objects in the world and changes in retinal stimulation. Essentially, these retinal changes must reveal invariant properties of the objects. However, in describing this proposal, O&N seem to want the theory to include not just flicks of the eyes, but also flicks of attention. But in what respect is a shift of attention *sensory*? If it does not change the retinal stimulation, how can it be the basis of a sensorimotor contingency?

Similarly, it is not clear that this model truly lacks internal representations and memory. The repeated appeal to "knowledge" of sensorimotor contingencies seems little different from an internal memory or representation of an object. The only difference from a traditional object representation is that the "knowledge" in this case is of dynamic rather than static information. It was for this reason that other attempts to eradicate memory from the process of perception argued that the invariant information underlying perception was present externally, in the environment (e.g., Gibson et al. 1969).

Gibson redux? The notion that manipulation of sensorimotor contingencies underlies perception and awareness is old, dating at least to behaviorist views. To quote an example from that era: "The awakening of a retained sensory impression when its response is made is memory in the common sense of the word. Thought, then, appears as a means of 'trying' different actions and anticipating their results through a process of automatic recall" (Ross 1933). Although **O&N** acknowledge the prior related work of several other authors, they pay surprisingly little attention to the one researcher who most (in)famously proposed these ideas: James Gibson. Both the content of the sensorimotor theory as well as the style of its exposition are highly reminiscent of Gibson's work on direct perception. Yet, O&N rarely mention these similarities, even when Gibson addressed the same issues extensively. For example, both Gibson and O&N argue that perception is exploratory, that it depends on detecting the constant information amidst change (invariants), that learning improves the detection of correlations, that temporarily occluded objects are "seen" (Gibson et al. 1969), and that vision does not rely on an internal representation of the world (see Gibson 1966; 1979/1986 for further details). Furthermore, both essentially define away classic problems in perception and cognition such as the binding problem (O&N), or perceiving depth (e.g., Gibson 1966, p. 298). Despite the overwhelming similarity between the approaches and their implications, O&N entirely neglect discussion of how their views differ from Gibson's, or of the ways in which their approach might better handle the many well-known critiques of direct perception (e.g., Fodor & Pylyshyn 1981; Ullman 1980). Given the similarities, it is not clear that O&N fare any better in the face of such critiques.

One fundamental difference between Gibson and **O&N** is the nature of the stimulus for perception. Gibson emphasized that the information for perception was available in the visual world rather than in the retinal stimulation. Observers generally do not become aware of the retinal sensations produced by objects – they are just aware of the objects. Although O&N appeal to similar notions, their argument relies more on invariants of the retinal stimulation as the basis for perception. This issue is perhaps most apparent in the discussions of seeing "red" and of "filling in." In these sections, the authors focus on how the brain might perceive changes to the retinal stimulation that result from moving the eyes, noting that the blind spot might provide additional information due to the changes in stimulation it imposes.

This approach has its pitfalls. For example, the theory is difficult to test empirically because it is affected by the nature of the sensory apparatus to a greater degree than Gibson's views. One advantage of Gibson's approach is that evidence for the presence and use of environmental invariants in perception could be taken as support for the theory. For Gibson, invariant information is present in the environment regardless of whether or not the perceiver is capable of "picking up" that information (Gibson 1966). For O&N, the information available for perception depends critically on the nature and structure of the sensory apparatus (at least in some cases – for other forms of sensorimotor contingency, they seem to appeal to a more Gibsonian view). The particular sensorimotor invariants that define red for one observer might then not be identical to those that define red for another observer. Although their approach to defining "redness" is clever and original, it is also untestable because no *laws* of sensorimotor contingency can be specified; their invariants are tied to the sensory apparatus and will not generalize from one observer to another. Not surprisingly, then, their paper lacks details about the nature of the contingencies that could underlie the perception of "red."

Concluding thoughts. The sensorimotor theory of vision is notable largely for its impressive breadth: it attempts to marshal a wide variety of evidence in support of its several ideas, and thereby attempts to explain (or define away) several longstanding puzzles about the nature of visual experience. Although individually these ideas are each intriguing**,** **O&N** do little to explain how they are interrelated and how the framework as a whole is structured. Consequently, evidence that is relevant to only one of aspect of the theory is often adduced as support for the whole. We have highlighted one example of this: whereas O&N claim that their theory is vindicated by their discovery of change blindness, we have argued that change blindness is entirely unrelated to claims about sensorimotor contingencies. Moreover, it provides little support for the more relevant claims about external memory. The lack of internal consistency, both of the framework as a whole and of its component ideas, leads to a view that is intriguing, but difficult to test empirically. Of course, some of these same objections have been applied to the quite similar views presented in Gibson's theory of direct perception (e.g., Ullman 1980).

In sum, the sensorimotor framework would be greatly clarified by considering in detail (1) which parts of the theory receive direct support from which types of empirical evidence, (2) which parts of the theory must stand or fall together, and (3) which parts of the theory are substantive departures from earlier Gibsonian arguments.[1]

NOTE

1. Following these suggestions might in some ways work in **O&N**'s favor by highlighting, for those who are not favorably disposed to the theory, which ideas needn't "go down with the ship." For example, we were intrigued by the idea of using sensorimotor contingencies to explain the difference between the various sensory modalities, but as it stands it is not apparent from the text that you can accept this idea while denying most of the other major claims.

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The absence of representations causes inconsistencies in visual perception

Jeroen B. J. Smeets and Eli Brenner
Vakgroep Fysiologie, Erasmus Universiteit Rotterdam, NL-3000 DR Rotterdam, The Netherlands. **smeets@fys.fgg.eur.nl**
brenner@fys.fgg.eur.nl **www.eur.nl/fgg/fys/people/smeets.htm**

Abstract: In their target article, O'Regan & Noë (O&N) give convincing arguments for there being no elaborate internal representation of the outside world. We show two more categories of empirical results that can easily be understood within the view that the world serves as an outside memory that is probed only when specific information is needed.

In line with the arguments in the target article, we consider vision to be tightly coupled to motor control. In order to catch a ball, one needs information about its size, weight, position, speed, and direction of motion. These attributes are important for different aspects of the action, so that they can be determined and processed independently within what has become known as separate visuomotor-channels (e.g., Jeannerod 1999).

Although determining visual attributes independently might be useful for controlling actions, this does not mean that the outcomes are independent, because the laws of physics and geometry relate many of these attributes. For instance, if an object moves at a certain speed, its position will change at a corresponding rate. An internal representation of the outside world would combine all available information to yield the most likely (and thus consistent) representation. This would of course reflect the physical and geometrical relationships within the outside world. The consequence of independent processing is that the relevant sources of information are combined separately for each attribute. Physically related attributes might thus be determined on the basis of different sources, within physiologically independent pathways. If all attributes are determined veridically, this independence remains unnoticed. It becomes evident when the processing of one attribute is erroneous, as is the case in visual illusions (Smeets & Brenner 2001). Two examples clarify this.

For intercepting a moving object one needs information about its speed to regulate the timing of one's action, and information about its (egocentric) position to direct one's action. Due to the noisiness of extraretinal information on eye orientation, the most accurate estimate of object speed will generally be one based on relative retinal information (Smeets & Brenner 1994). For determining an object's egocentric position, the use of extraretinal information cannot be avoided. And indeed, moving a visual background influences the perceived speed, without influencing the perceived position (Duncker illusion). In our view, each such attribute is processed independently to control a certain aspect of our actions. The Duncker illusion therefore affects the timing of ones action, without influencing its direction (Smeets & Brenner 1995).

A similar reasoning holds for grasping an object to pick it up. To move the digits to the object's surface, information about positions on that surface is needed (Smeets & Brenner 1999). To subsequently apply adequate forces to lift the object, a visual correlate of the object's weight is needed: that is, its size (Gordon et al. 1991). As with the previous example, these geometrically related aspects (positions and size) might very well be determined on the basis of different sources of information. The positions will again be determined using extraretinal information, whereas the object's size might be determined purely on the basis of retinal information. This explains why illusions of size affect the lifting force in grasping, but not the grip aperture (Brenner & Smeets 1996).

Independent processing of physically related attributes is not only evident in the visual control of action, but also in conscious perception. For instance, if one looks for a while at a waterfall, and subsequently fixates a tree at eye-level near that waterfall, the tree appears to move upward. The apparent position of the tree remains approximately at eye-level. Other examples of inconsistencies can be found in visual illusions, such as the Müller-Lyer illusion. This illusion influences the perceived size of the figure without affecting the perceived positions of the end-positions (Gillam & Chambers 1985). In analogy to the claim that we process only one fragment of the world at a time (sect. 4.2), this apparent inconsistency suggests that conscious perception involves processing only one attribute of that fragment at a time.

If one accepts that not all attributes are processed at a time, one can understand the flash-lag effect (e.g., Nijhawan 1994). This effect manifests itself when a subject is fixating a screen on which a target is moving continuously while another target flashes. If the subject is asked to indicate the position of the moving target at the time of the flash, he will misjudge this position in the direction of the target's motion. This has been interpreted as the result of motion extrapolation. However, this cannot be so because if the target unexpectedly reverses direction near the moment of the flash, the misjudgements are never beyond the actual trajectory of the moving target. It is more likely to be caused by different processing times for flashed and continuously presented stimuli (Whitney & Murakami 1998).

However, there is no reason to assume that flashes are processed more slowly than continuously visible stimuli. What then is the cause of this apparent difference in processing time? If not all attributes are processed continuously, the position of the moving target will have to be probed at some instant. This presumably takes time, and can start only after the flash has been detected. The moving target's position (or other attributes such as its colour and shape) will be probed too late. If this explanation is correct, the flash-lag effect should disappear if we change the experiment in a way that allows the position of the moving target to be probed at the time of the flash. A simple way to do so is to provide an additional cue for the time (or equivalently, the position of the moving target) at which the flash will occur. Indeed, the flash-lag effect is reduced markedly when this is done (Brenner & Smeets 2000).

Re-presenting the case for representation

Benjamin W. Tatler
School of Biological Sciences, University of Sussex, Brighton, BN1 9QG United Kingdom. **b.w.tatler@sussex.ac.uk**
http://www.biols.susx.ac.uk/resgroups/scn/vision

Abstract: O'Regan & Noë (O&N) present the most radical departure yet from traditional approaches to visual perception. However, internal representation cannot yet be abandoned. I will discuss: (1) recent evidence for very short-term pictorial representation of each fixation; (2) the possibility of abstract representation, largely unconsidered by the authors; and (3) that sensorimotor contingency theory requires internal visual retention and comparison.

O'Regan & Noë (**O&N**) extend the implications of recent change detection studies by arguing that not only is it unnecessary for the visual system to construct a point-by-point pictorial representation of the world across multiple fixations, but that no such information need be internalised on even the shortest of time scales. However, the reader should be cautious before abandoning all notion of representation and should first consider some of the implications of this model and other possible accounts.

Whilst it would be hard to argue that we build up a point-by-point pictorial representation over multiple fixations, there is evidence to suggest that a much shorter-term version might well exist. Contemporary accounts of visual perception often include a very short-term pictorial component (e.g., Rensink 2000). **O&N** would argue that these models represent a reluctance to depart from old ways of thinking about vision, but there is considerable evidence in recent literature to support the notion of a pictorial representation that survives only in the order of a fixation duration. Recently I studied what subjects can report about their fixations during the real life activity of making a cup of tea (Tatler 2001). Whilst making tea they were interrupted by the lights being turned off and asked to report details of what they were fixating. Subjects were able to report accurately the content of their fovea for the fixation interrupted by the lights going out, but were unable to report the content of previous fixations. This result suggests that detailed pictorial information is available to subjects within the current fixation but does not survive multiple fixations. The data further suggest that the locus of the subject's report is not the retina but a low-level buffer in which a veridical copy of the retinal image survives until it is overwritten soon after the start of the next fixation. In a recent change detection experiment Becker et al. (2000) support the notion of an iconic store that is overwritten by each new fixation. De Graef and Verfaillie (2001a) use post-saccadic masking to argue that pictorial representations of the retinal image are routinely established, but overwritten in the first 50 msec of each fixation. These empirical studies cannot be explained easily if we disregard all notion of internal pictorial representation, as O&N would like us to do. It should be noted, however, that O&N's model need not exclude the possibility of a very short-term pictorial representation and that many of their arguments could be equally compelling if they were to embrace the existence of such a representation.

In presenting their case for the "World as an Outside Memory" (WOM), **O&N** argue that no vestige of the visual environment need ever be internalised. It is certainly the case that when we require detailed inspection of a particular part of the world we simply direct our high-resolution foveas to that location. This observation lends support to the WOM model, but also raises some concerns particularly when we consider that it is not unusual for very large gaze shifts of up to 140º to be made in the real world (Grealy et al. 1999; Land et al. 1999). These large gaze shifts can locate items and positions with considerable accuracy, an achievement that is surely beyond the limits of our peripheral vision. In these situations it is hard to explain saccade targeting if we take the authors' stance in supposing that no aspect of the visual environment is ever internally registered. Although I agree that there is no need for a detailed pictorial representation of the whole scene, it seems that some more abstract record of the environment may well be required for our operation in the real world. This echoes the feelings and findings of many current researchers (e.g., Rensink 2000; Simons 1996) and O'Regan has, in the past, proposed the retention of more abstract details of the visual environment (O'Regan & Lévy-Schoen 1983). The present account could easily encompass the existence of an internal abstract representation of the world if we do not take such a hard-line view on the WOM model of perception. It is surprising that the authors do not give due consideration to the possibility or implications of abstract representations in their construction of the current model.

O&N's sensorimotor contingency (SMC) theory is a provocative and innovative attempt to account for many aspects of visual perception in the complete absence of internal representation. The theory proposes that perception is based upon the knowledge of changes to retinal stimulation as a result of world- or ego-motion (actual or potential), and so is an extension of the Gibsonian view of perception. Let me highlight one key issue raised by the SMC account. The authors consistently argue against internal registration and retention of the retinal image and yet the SMC theory critically relies upon comparisons of the retinal stimulation across viewpoint changes. If there is no visual retention or internal registration, how can we ever make these comparisons or build up knowledge of the structure of changes that occur for given eye movements on objects? Hence, how can we establish the laws of sensorimotor contingencies that are so vital to O&N's theory? This point warrants further exploration by the authors if they wish to retain their strong position of supposing that visual details are never internalised.

O&N's account of visual perception in the complete absence of internal representation is provocative and well-presented, and representative of the changes in our approach to visual perception that are necessary in the light of the recent descriptions of change blindness. Certainly we should all entertain these possibilities in our considerations of visual perception, but we must be cautious not to adopt a position that is equally as extreme as the old ideas of a complete internal picture. There is ample evidence and possibility within the current framework for very short-term pictorial representations and persistent abstract representations of our visual environment.

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Still room for representations

Robert Van Gulick
Department of Philosophy, Syracuse University, Syracuse, NY 13244.
rnvangul@syr.edu

Abstract: One can support O'Regan & Noë's (O&N's) commitment to the active nature of vision and the importance of sensorimotor contingencies without joining them in rejecting any significant role for neurally realized visual representations in the process.

O'Regan & Noë (**O&N**) offer an importantly different perspective on vision and visual awareness, which aims to challenge not only the standard answers in the field but many of its questions as well. Their own view comprises both positive and negative claims. To the positive, they ably demonstrate the importance of sensorimotor contingencies in visual perception. Negatively, they deny that visual perception involves the construction of a neural representation of the environment. However, the latter does not follow from the former, at least not without the addition of controversial assumptions about visual representations, for example, that they would have to be complete and unified. Thus, one might accept the major role the authors accord to sensorimotor contingencies but still believe that vision and visual experience involve some form of neural representation. Indeed, reflection on the sensorimotor model might lead one to just such a belief.

The disagreement turns in part on what one takes the representational model to entail, and **O&N** seem at times to pack a lot of heavy and dubious baggage into it. For example, they regard the results from inattentional and change blindness studies as weighing against the representational model. Some, no doubt, hold a naive view of visual representations as complete detailed depictions of the entire scene, but the representational model itself carries no such commitment. One can agree that at any given instant the perceiver gets detailed information about only a small portion of the surround, but still invoke neurally based representations to explain how all the relevant information is realized, at whatever degree of resolution. Nor do visual representations require a viewer, a homunculus in the inner theater, as O&N imply. According to many representational theories, the perceiver does not observe or "view" the representations. She sees external objects, but her ability to do so is underlain by neural features that function as representations of the scene.

Thus, we need to be clear about what something must do to "function as a representation" in the relevant context. Are representations in that sense compatible, incompatible, or perhaps even entailed or strongly implied by the sensorimotor model of vision? **O&N** view the perceiver as dynamically coupled to her environment; indeed they argue that such coupling is what vision consists of. It does not merely accompany or result from vision; it *is* vision. Anyone who takes a teleo-pragmatic view of mind (as I do), will find the active practical aspect of their model attractive. But one might still stop short of accepting the constitution claim: "That's all vision is"; or of drawing general negative conclusions about the lack of any role for representations in the process.

Consider the familiar guided missile example they use. The missile's pursuit is guided by the sensorimotor coupling between it and its target. Its success depends on its being accurately tuned to the contingencies that govern that coupling. According to **O&N** the successful operation of such a visually coupled process of agent/environment interaction involves nothing that functions as a representation of the target or the scene. Whatever information that missile acquires about its target is realized solely in the structure of their coupled engagement; vision, as they say, is a form of action. But consider real cruise missiles that evade radar detection by flying low and hugging the terrain. They are responsively coupled to their immediate environment, but their "look-down" system is used to navigate and identify its location and course by matching current imaged landforms against stored "maps" of the terrain. In such cases, there seems good reason to think that both the stored terrain maps, and the processing outputs that are matched against them, function as representations.

O&N must take care not to repeat the error of behaviorists. Having recognized that perceptual systems are a means to the goal of adaptively modifying behavior, behaviorists drew the false conclusion that learning is just the learning of behaviors. But, as many famous experiments showed, rats acquire a detailed knowledge of the spatial layout of their environment in the absence of any significant present behaviors dependent on such spatial facts. What the rat gains is not behaviors but information that might be of relevance to a wide range of future behaviors.

Somewhat analogously, **O&N** seem to go too far when they propose to identify vision with the successful coupling that takes place during a visually mediated engagement. There is indeed continuous sensorimotor feedback which shapes the response in a way that harmonizes with the environment. But vision seems also to involve the acquisition and storage of information for future use by means of the sorts of representations they are eager to deny.

Consider **O&N**'s examples of "ash can art" in Figure 2. They use those examples to show how poorly subjects remember and distort the scene in their memory-based drawings, and thus, perhaps, also how incomplete and schematic the subjects' perception of the scene can be. One can grant all that, but still note that the copies are more accurate than inaccurate, despite having been produced in the absence of visual access to the originals. The natural explanation is that by viewing the originals, the subjects were able to lay down a representation – incomplete and uneven in detail though it might be – that could be retrieved through imagistic memory in a form accurate enough to guide the intentional action of drawing a copy.

Moreover, that same information could have been applied to a wide range of behaviors other than copying, which illustrates a general feature of representational processes. As organisms move away from sensorimotor links that subserve particular behaviors, they develop structures that carry information in a form accessible to an open-ended range of applications. Rather than acquiring a set of interactive contingencies of the sort needed to guide a specific behavior, they store information in a format that can be applied in a diversity of ways, should the situations arise. I don't want to beg the question against **O&N**, but I am hard pressed to see why taking the sensorimotor aspect of vision seriously should lead one to reject such plausible representationalist models.

In search of the ultimate evidence: The fastest visual reaction adapts to environment, not retinal locations

Boris M. Velichkovsky and Sebastian Pannasch

Psychology Department, Dresden University of Technology, D-01062 Dresden Germany. **velich@applied-cognition.org**
www.applied-cognition.org **pannasch@applied-cognition.org**
www.applied-cognition.org

Abstract: The sensorimotor account of perception is akin to Gibsonian direct realism. Both emphasize external properties of the world, challenging views based on the analysis of internal visual processing. To compare the role of distal and retinotopic parameters, distractor effect – an optomotor reaction of midbrain origin – is considered. Even in this case, permanence in the environment, not on the retina, explains the dynamics of habituation.

The target article presents a refreshing synthesis of hitherto separate research, but it also creates a déjà vu impression. Every forty years, somewhere in the world, there is a rebellion against passive, mirror-like theories of cognition. For instance, a sensorimotor treatment of perception was the established approach in Russian "psychology of activity" (see Velichkovsky et al. 1973). In the '60s, labs around Leont'ev and Luria tried to implement ideas of an activity-based approach to perception and even to find eye movements (presumably in the tremor range) which could explain color perception, however without much success at that time.

In this commentary, we describe new data relevant to the world-as-its-own-model hypothesis. If there is a neurophysiological transition from proximal to distal representations somewhere in the brain, what does it mean for perception? **O'Regan & Noë** (**O&N**) deny the relevance of such a transition, basically in line with the Gibsonian argument. This argument may not always be conclusive in their case. All phenomena considered by O&N involve cortical processing that can include not just one but several transitions from retinotopic to spatial coordinates; hence, it is rather tempting to relate them to phenomenal perception.

Of interest, therefore, is the much simpler phenomenon of the distractor effect. This (also known as the "remote distractor effect") refers to an inhibition of a saccade or – what is the same in a free visual exploration – to a prolongation of the current fixation after a sudden visual event (Levy-Shoen 1969; Walker et al. 1997). With its reaction time of only 100 msec, the distractor effect is the fastest optomotor reaction in humans. This effect is also evoked by acoustic signals, so it could be related to orienting reaction (Pannasch et al. 2001).

As a symptom of orienting reaction the effect should habituate, that is, become habitual – but there was no sign of a habituation in our experiments. One possible reason could be that we used a gaze-contingent paradigm presenting distractors in the same area of the retina. In a new experiment, we compared distractors' efficiency over time when they appeared either in the same retinal location (variable localization in the world) or in the same place of the picture (variable retinal location). Full-screen copies of nineteenth century paintings were presented to the subjects on a 17-inch computer monitor with instructions to study them for a recognition test. After the initial phase of 20 sec, distractors (circular patterns of 4 degrees diameter) appeared within approximately every seventh fixation. Distractors were presented for 75 msec either in the lower right part of the picture, 12 degrees from the center, or in the respective location of visual field. In addition, they were presented 50 or 150 msec after the start of fixation. After 12 distractors, the first picture was replaced by the next picture, and so on. Conditions were partially counterbalanced across 6 subjects and 4 pictures.

Figure 1 shows the main results. No effect is observed either in space or in retinal coordinates for 50 msec delay. For 150 msec and permanent localization in the picture, there is a clear distractor effect as well as two habituation effects – between pictures

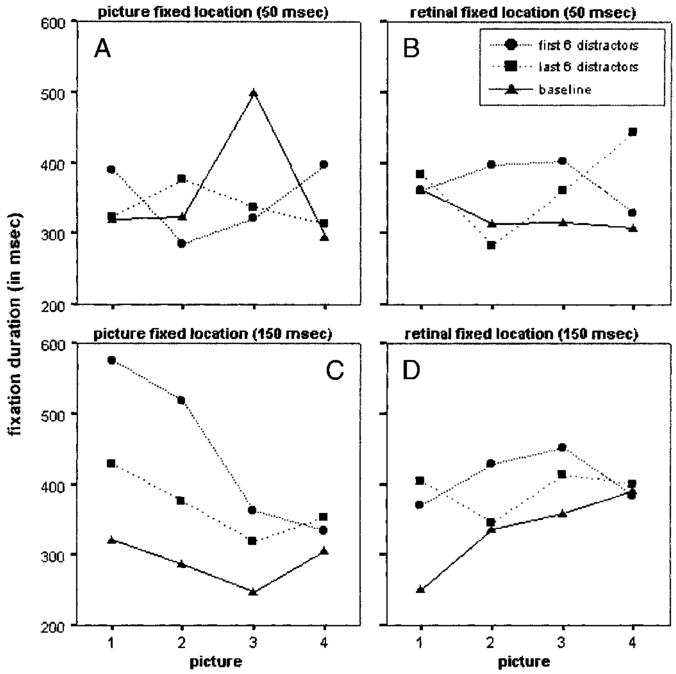

Figure 1 (Velichkovsky & Pannasch). Fixation duration for the first vs. last distractors and the baseline: Top left: distractors appear 50 msec after begin of fixation in the same picture location; Top right: 50 msec delay, same retinal position; Bottom left: 150 msec delay, same picture location; Bottom right: 150 msec delay, same retinal position.

[$F(3,6) = 6.29$, $p < .001$] and between the first 6 and last 6 distractors within the first three pictures [$F(1,6) = 5.82$, $p < .024$]. In the case of the same retinal location, there is a significant distractor effect [$F(1,6) = 11.48$, $p < .001$], however it does not change over time.

According to a recent analysis, the distractor effect seems to be mediated by midbrain optomotor circuits (Reingold & Stampe 2000). They are retinotopically organized and too fast for an involvement of higher-level representations. Our results demonstrate that in this case the permanence in space, that is, in the outside world not on the retina, causes the decline in the saccadic inhibition. The decline can be explained by a genuine habituation or by a form of adaptation mediated by sensorimotor activity: distractors with an invariant position in the world are more easily explored and lose their novelty more quickly. It is interesting that adaptation effects are observed only at longer delays. This testifies to the fact that the environmental dependency is not due to an immaterial symbolic act. Rather, every re-fixation initiates the process of spatial localization anew, and the process obviously needs some time to be completed (Bridgeman et al. 1994). The generality of this process is remarkable, as is its potency across the vast range of the brain's evolutionary mechanisms.

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Perceptions as hypotheses of the outside world

Veijo Virsu[a] and Simo Vanni[b]

[a]*Department of Psychology, University of Helsinki, FIN-00014 Helsinki, Finland;* [b]*Centre de Recherche Cerveau et Cognition, CNRS, Universite Paul Sabatier UMR 5549 133, 31062 Toulouse cedex, France.*
veijo.virsu@helsinki.fi **vanni@cerco.ups-tlse.fr**

Abstract: Perceptual phenomena reviewed by O'Regan & Noë (O&N) cannot be explained by bottom-up activity alone, but conventional interpretations suffice if perceptions are seen as activations of memory models of the outside world and its events. Motor involvement is necessary only during the phylogenetic and ontogenetic development of perceptual mechanisms.

O'Regan & Noë (**O&N**) argue that signal activity of the brain alone, without considering the outside world and exploratory actions, is not sufficient to explain visual perception. For example, it can be shown that the visual perception of objects and features correlates with the activity of the lateral occipital cortex (Vanni et al. 1996), parieto-occipital alpha and mu rhythms (Vanni et al. 1997; Vanni et al. 1999), or the sustained activity in the V5 complex (Uusitalo et al. 1997). According to the notion of O&N, results like these are not causally related to perception. What, then, motivates experiments on neural correlates of perception? What should be added in order to explain perception?

O&N answer the second question but they do not provide a suitable answer to the first one, perhaps because their framework does not allow it. The framework presented by O&N is suspect, however, because it cannot deal with perceptions such as pain, migraine fortification illusions, or phantom limbs and related perceptual peculiarities, which do not have any sensorimotor involvement. For the auditory and somatosensory percepts this is even more evident. We can understand speech, or experience music, without moving our ears or body.

O&N submit afferent neural representation as a competitor of their framework. It is easy to show neural representation as untenable with the perceptual phenomena they review. A much harder adversary is the approach going back to Helmholtz, who assumed that perceptions are based on unconscious and involuntary inferences concerning the properties of objects to be perceived (see Southall 1962). Gregory (1972; 1980) developed this notion by assuming that perceptions are hypotheses tested by thinking: the source of hypotheses is ideation and memory models. This framework can probably explain all the data presented by O&N without being at any variance with the conventional interpretations. For example, a visual activation occurs in the putative parieto-occipital sulcus after an eye blink (Hari et al. 1994) or saccadic eye movement (Jousmäki et al. 1996). These activations may represent signals that are necessary for preventing the disturbance of hypothesis testing caused by irrelevant movements. The hypothesis testing is based on relevant information present in all sensory systems, context, memory, intended and executed actions, and so forth.

What are these hypotheses? Psychologically speaking they are models of the outside world and its events as they are supposed to be. They are not abstract concepts or "images in the head." Physically, they are extremely complex activation patterns in neural networks. They result from anatomical connection weights, afferent stimuli, and recurrent activities that reflect attentional selection, memory, and thinking. The selective activation of only a subset of neurons, which depends on the task at hand, minimizes the computational load and energy consumption of the brain. This notion assumes no special role for sensorimotor events and contingencies, movement, or action, although they can modify perceptual mechanisms as the prism experiments reviewed by **O&N** show.

O&N's article does not indicate how sensorimotor contingencies affect the limits and variations of vision, or how visual mechanisms originate. Although sensorimotor contingencies might have played a decisive role in the development of the computational hardware of the brain, they are not a prerequisite for vision any longer when the mechanisms are actually used. The connection strengths between neurons are largely built up during ontogenesis, but the evolution of the mechanisms should not be forgotten.

Virsu and Hari (1996) have given a quantitative example of how a locomotion-based magnification factor from the retina to cortical areas can evolve. They derived a realistic approximation of the magnification factor assuming only that the same amount of cortical visual apparatus was used by our walking ancestors for analyzing the visual world at different eccentricities. As this mechanism exists now, it automatically and extremely rapidly performs the hardware computation of several invariances of spatial vision. It also determines the variations and limits of vision for a large number of spatial, spatiotemporal, chromatic, and attentional variables across the whole visual field (see Carrasco & Frieder 1997). Thus the mechanism yields preprocessed data for hypothesis testing.

Movement-dependent evolution and ontogenesis (see Held & Hein 1963) may explain even quantitatively how the computational hardware mechanisms of perception have developed, but this does not mean that there is anything "motor" in the hardware any longer, not even when the mechanisms can guide reflex movements. Vision at the present, conscious or not, is possible without motor acts or their preparation, and movements can be ballistic without feedback from sensory data. Motor acts cannot exist without memory involvement, but perception can exist without motor acts, solely on the basis of memory and hypothesis testing. Neural correlates of visual perception emerge from the brain mechanisms that are utilized in perception, independently of their possible origin in motor acts. In sum, the study of neural correlates produces essential information about the mechanisms of perception, independently of sensorimotor contingencies.

A non-epistemic, non-pictorial, internal, material visual field

Edmond Wright

Faculty of Philosophy, University of Cambridge, Cambridge CB3 9DA, United Kingdom. **elw33@hermes.cam.ac.uk**

Abstract: The authors O'Regan & Noë (O&N) have ignored the case for the visual field as being non-epistemic evidence internal to the brain, having no pictorial similarity to the external input, and being material in ontological status. They are also not aware of the case for the evolutionary advantage of learning as the perceptual refashioning of such non-epistemic sensory evidence via motivated feedback in sensorimotor activity.

On the one hand, the authors **O'Regan & Noë** (**O&N**) somewhat ingenuously, admit that they did not set out to refute "the philosophical opposition" (sect. 6.9, para. 4). On the other hand, with an argument F. H. Bradley used (see Price 1961, p. 127), they choose to attack repeatedly a philosophical claim about internal representational projection which can be dated as far back as the nineteenth century: typically, that of Bradley's target, Thomas Case (Case 1888, p. 25). But there have been many obvious and detailed rejections both of Case's view, and of Bradley's objection to it, by supporters of another type of internal field (Alroy 1991; Lowe 1981; 1996; Maund 1975; 1993; 1995, pp. 25–49; Sellars 1922; Wright 1975; 1990, pp. 82–84; 1994, pp. 483–86; 1996, pp. 23–28).

Take the authors' claim that all supporters of an internal presentation are committed to there being "red neurons" in the brain. This is rhetorically parallel to Bradley's complaint that Case was committed to the claim that "when I smell a smell I am aware of the stinking state of my own nervous system" (see Price 1961, p. 127). Roy Wood Sellars was the first to present the theory that the relation between sensory inputs and their presentation in the brain is not a copy but that of a "differential correlation" (Sellars 1932, p. 86), and that therefore, for the visual system, *there is no pictorial resemblance between the input and the cortical presentation.* "Sensuous contents are not *like* what controls their rise" (Sellars 1919, p. 414; his emphasis). This "structural isomorphism" implies that a colour experience will bear some relation (e.g., to intensities, wavelengths, etc.), not necessarily in direct ratio, to its causes, both near and distal, which will not be "coloured" at all. This also disposes of the ancient Homunculus Objection (first used by Hermann Lotze 1884, pp. 492–93, relied on by the authors, sect. 5.4, para. 3) since the internal sensing is obviously not done with eyes, which have evolved to pick up the uncoloured light-rays. Obviously, then, there cannot be, within this theory, any "pictures in the brain" *for pictures are actually uncoloured.* Sensing, of whatever kind, is a direct neural experience. Incidentally, the authors appear to be confident that external space is stereoscopically three-dimensional; but stereoscopic space is also a sensory feature (it can be turned inside out: Nakajima & Shimojo 1981), and, furthermore, there is no guarantee from physics that real space is three-dimensional (Stewart 1986). So the internal response-field is involuntary, non-mental, hence material, *evidence,* and does not carry *information* about "the characters of objects" (sect. 2.4, para. 3). It is like a footprint – material evidence, but not literal information, open to guesses about its causes.

There is much empirical support for the basic non-epistemic state of sensory fields (see my extended discussion, Wright 1996, pp. 24–28). Josiah Royce gave an example of the non-epistemic in 1885 (Royce 1958, pp. 309–10; see also Arthur W. Collins 1967, p. 455, for the first use of the term). Another counter-example is my After-Image Argument (Wright 1983, pp. 57–62), which no one has yet tried to refute: it is an example of an experience which does not "look like anything" (target article, sect. 5.11, para. 6), yet which is still plainly sensed, in colour, and *after a while* does come to look like something. One might mention here that it is empirically false to state that when one closes one's eyes, one sees "a blank" (sect. 2.1, para. 5): I have just tested this, having seen the background colour of light through my eyelids, after-images of what I last looked at, and, being a good visile, mental imagery, which I may *or may not* find objectifiable. It is also weak to suggest that a belief in qualia is not widespread (sect. 6.9.2); I have found many non-philosophers who find it the reverse of counter-intuitive.

What is fundamentally odd about **O&N**'s approach is that they praise Jean Piaget's view of the importance of the sensorimotor feedback in vision (sect. 2.2, para. 4), but he is a constructivist, for whom "to know is to assimilate reality into systems of transformations" (Piaget 1970, p. 15), in which actions are "added, *reordered,* sequenced, related" (p. 17; my emphasis). Constructivism sees "entities" as the organism's ongoing, *adjustable* selections for action from the real evidence that is sensory experience, not as already given units in the external real as the authors here "magically" view them. It sees the real continuum as existing, both as sensory evidence and as its external causes, but objects and persons – "objective reality" – only as viable selections from that evidence (as to why we are often unhappy with that thought, see Wright 1992, pp. 47–50). The incessant intersubjective updating of concepts that goes on under the regime of motivation, even that of persons themselves, proves simultaneously *the existence of the evidence,* both as internal field and external cause, as against *the tentativeness of objectivity,* and this without sliding into solipsism (*a fortiori* because the self, as any "entity," is corrigible from outside itself). We only achieve what Stevan Harnad calls "convergence on approximations" (Harnad 1987, p. 537). Those selections have the viable character of a hypothesis without being consciously so (Gregory 1993, pp. 256–60). To use **O&N**'s own words against themselves, we only "*take* ourselves *to be* embedded in the environment" (sect. 6.7, para. 2, my emphasis), for they mean the *objective* environment, the "reality" that we "take to be" certain, not the material real, disturbingly contingent, in which we *are* embedded. The nature of the internal field as sketched above has therefore the *evolutionary* advantage of being open to constant updating from the non-epistemic evidence, even in the singularity of the "entity." As the sixth-century Indian philosopher Dignaga sensibly said, "Even 'this' can be a case of mistaken identity" (Matilal 1986, p. 332). There is not space to bring out the scope and fertility of this theory (see Wright 1990, pp. 85–87; 1999; 2000; 2001), but the authors might yet see that there is some justification for Gregory Harding's claim, that a place for qualia must be found in "a richer conception of the physical" (Harding 1991, p. 302).

Authors' Response

Acting out our sensory experience

J. Kevin O'Regan[a] and Alva Noë[b]

[a]*Laboratoire de Psychologie Expérimentale, Centre National de Recherche Scientifique, Université René Descartes, 92774 Boulogne Billancourt, France;* [b]*Department of Philosophy, University of California, Santa Cruz, Santa Cruz, CA 95064.* **oregan@ext.jussieu.fr**
http://nivea.psycho.univ-paris5.fr **anoe@cats.ucsc.edu**
http://www2.ucsc.edu/people/anoe/

Abstract: The most important clarification we bring in our reply to commentators concerns the problem of the "explanatory gap": that is, the gulf that separates physical processes in the brain from the experienced quality of sensations. By adding two concepts (bodiliness and grabbiness) that were not stressed in the target article, we strengthen our claim and clarify why we think we have solved the explanatory gap problem, – not by *dismissing* qualia, but, on the contrary, by *explaining* why sensations have a "feel" and why "feels" feel the way they do. We additionally clarify our views on: internal representations (we claim internal representations cannot explain why sensation has a feel), on behaviorism (we are *not* behaviorists), on perception and action (we believe there *can* be perception without action), and on the brain (we believe the brain *does* do something important in perception).

The aim of our target article was to explain perception and perceptual consciousness. Specifically, we sought to lay out a way of thinking about visual experience (indeed, about perceptual experience more broadly) that can address the *explanatory gap* for consciousness, that is, the problem of understanding how physical mechanisms can give rise to consciousness (to experience, sensation, feelings).

We are grateful to the commentators (including those whose commentaries were not accepted for publication in this issue). Their criticism forces us to clarify our position.

R1. Finding and closing the explanatory gap

Broackes, Block, Clark & Toribio, Cohen, Kurthen, Manzotti & Sandini, Lamme & Landman, Laming, Oberauer, Pylyshyn, Revonsuo, and **the Editor** doubt that the sensorimotor approach provides for a novel solution to the problem of the explanatory gap. We address this issue in this section by formulating more explicitly the reasoning implicit in the target paper.

The explanatory gap for perceptual consciousness has several aspects. Following Hurley and Noë (forthcoming), we can distinguish three different questions that need posing (cf. Chalmers 1996, pp. 234–35).

1. The intra-modal comparative aspect: Why does it look like *this* (spherical, say), rather than like *that* (say, cubical)?
2. The inter-modal comparative aspect: What makes one experience *visual* whereas another is tactile?
3. The basic question: Why is there experience at all?

It is clear that the sensorimotor approach makes a contribution to (1) and (2). As for (1), the intra-modal aspect, consider that the differences between a spherical and a cubical object of sight correspond in part to differences in laws of sensorimotor contingency. For example, there are systematic changes in the character of the profile of a cubical object as you move around it. These patterns of changes are totally unlike the changes in sensory stimulation that occur as you walk around a sphere. The visual quality of *looking cubical* is constituted (at least in part) by your knowledge of how your visual stimulation will change as you move around it.

Int*ra*-modal differences pertain to differences in the objects of sight. Int*er*-modal differences pertain, rather, to the differences in what you do when you encounter objects through different sensory modalities. Moving your eyes to the left or right will produce a change in sensory stimulation related to an object if that object is being visually perceived but not if it is being tactually perceived, or if it is being listened to. Likewise, stopping and unstopping your ears affects your relation to things you are hearing, but not your relation to things you are seeing. In general, in agreement with a suggestion made previously by Pacherie (1999), we argue that the sensory modalities differ from one another in that they are governed by different laws of sensorimotor dependency.

But what of the basic question (3)? Can the sensorimotor approach explain why activity drawing on knowledge of sensorimotor contingencies gives rise to experience at all? Several commentators challenge us on this score. **Clark & Toribio**, for example, write that "Even if the contents of our conscious visual experiences reflect ways of acting in the world, the hard problem surely remains." **Oberauer** asserts that we are victims of the illusion of thinking that sensorimotor contingencies can do something that neural representations cannot, namely explain the emergence of consciousness. **The Editor** writes: "The point is that what is seen is felt, not merely registered, processed, and acted upon. To explain consciousness in terms of sensorimotor action, one has to explain why and how any of that processing is *felt*. . . ."

To make some headway, let us consider a fourth question about the explanatory gap, this one intermediate between questions (2) and (3).

2′. The perceptual aspect: What is the basis of the difference between perceptual and nonperceptual awareness of a thing? The contrast here is between conscious states with sensory qualities and those without sensory qualities. To deal with (2′), compare your visual experience of a book on the table in front of you with your nonperceptual awareness of a book on your desk in the next room. Two features sharply distinguish these two modes of awareness.

Bodiliness. Moving your body makes a difference to the mode of your awareness of the book in front of you on the table but not to the mode of your awareness of the book in the next room. In particular, it is not just any body movements that make a difference, but those that depend on the distinctively *visual* sensorimotor contingencies. For example, blinking, eye movements, body or head movements modulate your relation to the book in front of you but make no difference at all to the book in the next room. Furthermore, if you reach out to move the book, or wave your hand to obstruct it, or to cast it in shadow, there will be a change in way the book affects your sensory systems. Such movements make no similar difference to the way you are affected by the book in the next room.

Grabbiness. The visual system is put together in such a way that sudden changes in the visual field provoke an automatic orienting reflex. For example, if a mouse moves the book suddenly, or if the lighting on the book changes abruptly, this will grab your attention, and cause your eyes to flick to the book. Thus, movements or changes in the book immediately affect your sensory stimulation (just as movements of the body do): you are (so to speak) "connected" to the book. On the other hand, there is no such sensitivity to movements of the book in the next room.

Bodiliness and Grabbiness affect your relation to the book in front of you, but not your relation to the book in the next room. This is what the difference between perceptual awareness and nonperceptual awareness (or *thought*) comes down to. We suggest that it is precisely the way in which sensory stimulation is affected by movements of the body (bodiliness) and movements of (or changes in) the object (grabbiness), which give sensory experience its peculiar, *sensory,* character. In other words, bodiliness and grabbiness explain not only the difference between seeing something and merely thinking about it (thus answering 2′), but they also explain why seeing something has the sort of qualitative characteristics that it does. And crucially, bodiliness and grabbiness are concepts defined strictly in functional terms, thereby providing a functional basis for the difference between sensory and non-sensory experience.

With these considerations in place, we can now go further and try to make clear how, with bodiliness and grabbiness, the sensorimotor approach provides the key to closing the explanatory gap. Nagel (1974) says that there is "something it is like" to have a sensory experience. Let us be more precise and try to characterize exactly what it is like, taking visual experience as an example.

First, visual experience is **visual**, rather than, say, tactual or olfactory. Second, it is **forcibly present** to your consciousness. Third, it is **ongoing**, that is, the experience seems to be happening to you in a continuous way: its subjective character lasts while the experience continues. Fourth, the experience strikes us as **ineffable**, that is, though you experience it as possessing various qualities, the exact qualitative character escapes description in words.

We believe the sensorimotor approach allows us to explain each of these aspects of the quality of the experience. To the extent, then, that the experience itself is constituted by the presence of just these qualities, then the sensorimotor account can explain why the experience occurs at all (and so it can answer [3]).

First, as we have stated already, the **visualness** is explained by the character of the sensorimotor contingencies produced by exploration mediated by the visual apparatus and by the character of the sensory changes produced by objects as they move in space.

Second, the sense of **forcible presence** is explained by (1) grabbiness and (2) bodiliness. (1) the book forces itself on us as present because any movement of the book causes us to direct our attention (our processing resources) to it. (2) The slightest movement of the relevant parts of our bodies modifies the sensory stimulation in relation to the book. Metaphorically, it is as if we are *in contact* with the book.

Third, we can explain **ongoingness** in a similar way in terms of bodiliness and grabbiness. The sense of an ongoing qualitative state consists, (a) in our understanding that movements of the body can currently give rise to the relevant pattern of sensory stimulation (bodiliness), and (b) in our understanding that the slightest change in what we are looking at will grab our attention and in that way force itself on us. In this way we explain why it seems to us as if there is something ongoing in us without actually supposing that there is anything ongoing, and in particular, without supposing that there is a corresponding ongoing physical mechanism or process. Just as our awareness of detail present in the world is explained by the fact that we have *access* to that detail, and that we know that we do – this is the significance of the idea of the world as external memory (O'Regan 1992) – so our awareness of the experience as *ongoing* is explained by the fact that we encounter a sensory event whenever we look.

Fourth, the sensorimotor approach can also explain the **ineffability** of experience. The nature of our contact with objects of perception is determined by the very complicated laws linking commands given along thousands of motor nerves with the associated input received along thousands of sensory input fibres. Obviously these laws, though they are registered and distinguished by the brain, are not themselves what is available for use in our decisions, judgements, and rational behavior. We cannot describe the laws – all we can do is *put them to use.* Just as we can ride a bicycle, drive a car, and tie our shoelaces without being able to describe in detail everything these skills involve, our sense of the ineffability of experience is explained by the fact that we lack access to the very complicated laws governing sensorimotor contingencies involved in sensory exploration.

R2. Robots and chauvinism

We argue that the peculiar *sensory* quality of perceptual experience derives from the fact that the associated sensorimotor contingencies have bodiliness and grabbiness. However, to be perceptually aware of an object is not only to interact with it in ways drawing on knowledge of sensorimotor contingencies, it is to make use of one's skillful interaction for guiding behavior and other forms of thought and action (such as speech). This amounts to the requirement that, to actually visually *experience* an item, to see it, one must have a kind of higher-order control of one's tracking activity. This kind of control corresponds to the particular use we made of the term "awareness," or what Malcolm (1984) and Rosenthal (1997) have called "transitive consciousness"[1]: but note, crucially, that – like sensorimotor contingences themselves, – this control is a functionally describable capacity.

We could build a robot with knowledge of sensorimotor contingencies on the one hand, and with the further ability to make use of information about its exercise of this knowledge in its planning and acting, on the other hand. If indeed such a robot were to be embodied and situated in such a way that its perceptual encounters were characterized by bodiliness and grabbiness, then it would be correct to say – and the robot would agree! – that there is "something it is like" for it to perceive.

In this way we meet **Clark & Toribio**'s worry about ping-pong playing robots head on. They write:

> A good ping-pong playing robot, which uses visual input, learns about its own sensorimotor contingencies, and puts this knowledge to use in the service of simple goals (e.g., to win, but not by too many points), would meet all the constraints laid out. Yet it seems implausible to depict such a robot (and they do exist – see e.g., Andersson 1988) as enjoying even some kind of modest visual experience. Surely someone could accept all that O&N offer, but treat it simply as an account of how certain visual experiences get their contents, rather than as a dissolution of the so-called hard problem of visual qualia.

We agree that, at least as described, it is implausible that **Clark & Toribio**'s ping-pong playing robot would be perceptually conscious. But this is exactly what the sensorimotor approach would predict of such a robot. As it is described, it is simply *far too simple* to be a plausible candidate for perceptual consciousness of the kind usually attributed to animals or humans. This simplicity has several dimensions. For one thing, the robot lacks too much of the background capacities (intentions, thoughts, concepts, language) for the attribution of experiences to it to make much sense. For another, its sensorimotor mastery is reasonably supposed to be pretty simple in comparison with the exceedingly complicated effects of movement on the sensory systems of animals. Nevertheless, we would claim that once we imagine a robot that not only masters sensorimotor contingencies, but makes use of that mastery to engage with the world in a thoughtful and adaptable way, it becomes necessary to say that it has (at least primitive) visual experiences.

Block raises a similar objection to **Clark & Toribio**'s. He points out that the sensorimotor contingencies governing the visual experience of a person who was both paralyzed *and* almost completely blind would be simple enough that they could be programmed into a laptop computer. But it is plainly false, Block reasons, that the laptop would have the visual experiences enjoyed by the nearly blind paralytic. This is meant to be a *reductio* of the sensorimotor view. The argument fails, however, because it is *not* a consequence of our view that the laptop would have visual experiences like that of the nearly blind paralytic. The simplest way to show this is to consider that there is no reason to think that programing sensorimotor contingencies into the laptop would give the computer *knowledge of sensorimotor contingencies* in the relevant sense. By "knowledge" we mean practical mastery, that is, familiarity with the ways sensory stimulation varies as a function of bodily movement. It is difficult to see how a machine without a body could have this kind of know-how. Another relevant consideration is that, contrary to the laptop, a legally blind paralytic would be able to perceive in other sensory modalities. For example, when the incandescent object comes closer, you would feel its heat. Your limited visual stimulus would be correlated with nonvisual sensory stimuli. But there are other reasons to conclude that Block's laptop would not have perceptual consciousness. Importantly, the laptop lacks not only capacities for bodily movement, but also capacities for thought and perceptual *attention.* Suppose that Block's laptop were now endowed with understanding and with a body that functioned (to some degree) like ours. Of such a robot, it is surely conceivable (indeed probable) that it *would* be perceptually conscious.

These considerations are related to a second criticism advanced by **Clark & Toribio**, namely that of "sensorimotor chauvinism," namely, the view that only creatures with bodies exactly like ours can have experiences qualitatively like our experiences. They suggest, in response, that "there seems no a priori reason to believe that every difference in SMCs will make a difference to the experienced content, even if the SMCs (some of them, at some level) are indeed active in determining the content." As **Clark & Toribio** suggest, the key issue here is level. For instance, we argue that it is reasonable to think of Bach-y-Rita's TVSS as a kind of vision (quasi-vision, tactile-vision) because there is a level at which the laws of sensorimotor contingency governing vision operate in the domain of TVSS. Of course, TVSS proceeds without use of the eyes or the visual pathways – thus TVSS is a way of seeing only if we think of it at a sufficiently coarse grain. Our view thus allows for the judgment that creatures with radically different kinds of physical make up can enjoy an experience which is, to an important degree, the same in content and quality. But it also allows for the possibility (indeed, the necessity) that where there are physical differences, there are also qualitative differences. To this extent, our proposal deviates from classical functionalism. That is, we are rejecting a certain way of thinking about the multiple-realizability of functional systems. In particular, we hold, as Clark & Toribio are right to point out, that differences in our bodies (and thus in sensorimotor contingencies) will make a difference to our experiential states. One way to put our point is as follows: only a creature with a body like ours *could have* input/output relations like ours. We agree with the functionalists, though, that it is the input/output relations that matter. Moreover, we agree that it is not intrinsic qualities of the neural material which instantiate brain processes that matter for consciousness. What matters is the patterns of sensorimotor contingency.

R3. Are there qualia? What are experiences?

It was not our aim to deny that there is experience, nor to deny that experience has a qualitative character. Our aim, rather, has been to explain experience and to explain its qualitative character. We believe that once you have answered the various questions we answer in the target article – what makes a conscious state *perceptual* as opposed to *nonperceptual*? what makes an experience a *visual* experience as opposed to a *tactile* experience? what makes a visual experience an experience *as of a cube* rather than *as of a sphere*? what makes an experience have the qualities that are specific to sensation, namely, *forcible presence, ongoingness,* and *ineffableness* – there just isn't any qualitative residue left over which still needs explanation. If we use the term "qualia" to refer precisely to this sort of qualitative residue, we claim in the target article that there are, in this restricted sense of the word, no qualia. Let us add a few words of explanation here.

Consider the would-be quale that you enjoy when you see something red, for example. Strawson (1989) writes:

> Most . . . will agree that the notion of the qualitative character of colour-experience can reasonably be taken for granted. And for present purposes, a sufficient reply to those who disagree is simple, as follows. Consider your present visual experience.

Look at the bookshelf. (Get out some of the brightest books.) There you have it.

We are inclined to respond to this argument in two ways. First, we are inclined to point at the fact that our visual experience appears to us as being sensation-like (rather than thought-like, say) in that this experience consists precisely in being red (and not some other color, nor a sound or smell), and in that the experience imposes itself on us in a forcible and ongoing way. These are precisely the features of the experience that the sensorimotor view explains. The experience is *as of red* rather than *as of green* thanks to the subtly different patterns of sensorimotor contingency governing our encounter with the red surface (as compared to a green one). The presence and ongoingness of our experience consist in our continuous *access* and in our ever-ready *responsiveness* to the redness (i.e., to knowledge of sensorimotor contingencies with their associated bodiliness and grabbiness).

There is a second way we are inclined to respond to Strawson's argument. It is not at all clear what we are commanded to do. "Look at the bookshelf . . . . There you have it." When you look at the books, what do you encounter? The books. Do you encounter all of them all at once? No. But you have access to them all at once and wherever you do look you find a book. So you take them to be there in front of you and to be aware of them (in the sense that you are connected to them by laws of sensorimotor contingency that you understand). But all of this isn't something that *just happens,* as it were, *in a flash.* It is something you do. You move your eyes here, there, back and forth, now here, now there. You think about what you see. You notice this, are distracted by that. The experience you have looking at the books is not something that occurs in you or to you, it is something you do. And when you catalog what you do in acting out this experience, you don't need to count any additional residue over and above the eye movements and the books and their qualities (such as the red *quale*).

This idea is challenged by **Broackes** on something like Rylean, ordinary-language grounds. "The experience of swimming in the rain," he writes, "is something we get while performing that act. The swimming is something we do, the experience is not." Broackes' point seems to be that although having an experience often involves doing things such as exploring with your eyes, your fingers, sniffing your nose, and so on, the things that you do don't *constitute* experiences, rather they *provide* experience.

We agree that this is certainly what people say and believe. However, we suggest that people are wrong: in fact, your belief that you are in a special kind of "seeing redness" state (when looking at an apple, say) derives from the fact that you are connected to the redness in a special, very intimate way, by virtue of bodily, grabby sensorimotor contingencies. Any movement of your eyes produces a change in stimulation you are receiving from the apple. Any movement of the apple (or change, e.g., in its illumination) will grab your attention. It is *as if* we are in a state which is *saturated by the feeling of redness,* when in fact we are only poised and attuned and ready and expectant and capable.

It was taking this stance that allowed us to bridge the explanatory gap and to make a number of empirical predictions. This idea is at the core of our approach. Admittedly, it is counter-intuitive.

Broackes is certainly right that we move too fast against qualia when we say that qualia are meant to be properties of experiential states and there are no such states. Our dismissal of qualia was meant to apply only to the restricted notion of qualia conceived as the residue which cannot be accounted for from a functional approach. In particular, we can certainly agree with Broackes that standing for a few minutes in front of an Ellsworth Kelly painting can put you into a kind of perceptual "state" and keep you there. We deny, though, that there is any sense in which this supposed state is unitary. To be in such a "state" consists of several things. Your atttitude to the painting is organized by your thoughtfulness, your attentiveness, by the manner in which you look at the picture and reflect on it. We believe that even when we stop to appreciate the redness in the painting, say, we are not "receiving" an atom-like quale. Instead, we are at that moment integrating into our rational behavior, our current mastery of the sensorimotor contingencies of red.

Blackmore criticizes our account of qualia from a different perspective, namely, the standpoint of Dennettian skepticism about consciousness. She cites Dennett (1991) with approval: "the actual phenomenology? There is no such thing." And she presses against us the thought that in admitting that there are facts of the matter about perceptual phenomenology, we are sliding back into the Cartesian Theater. **Dennett**'s heterophenomenological perspective is a rich, provocative, and important one. Its strength consists in its ability to take on board all the offerings of first-person reflection while dissociating those offerings from claims to privilege or metaphysical insight. It may be – indeed, it is likely – that our phenomenological analysis can be accommodated by heterophenomenology.

R4. Are we behaviorists?

Block, Harnad (the Editor), **Kurthen, Cohen** venture the criticism that ours is just a new version of (a tired old) behaviorism. This criticism might seem plausible insofar as we deny that there are qualia (in the restricted sense of *an inexplicable qualitative residue:* see sects. 6.3, 6.4 of the target article and R3 above) and we assert that we can explain perception in terms of patterns of interdependence between stimulation and action (which certainly has a behaviorist stimulus-response ring to it). But there are important differences between our view and any version of philosophical behaviorism with which we are acquainted. First, as stressed in R3 above, we do not deny that there are experiences or that experience has a qualitative character. Second, our theory takes as primitive the idea that perceivers have *knowledge* of sensorimotor contingencies. The basis of the qualitative character of experience, in our view, is the perceiver's *knowledge* of the interdependence between stimulus and bodily movement. Third, according to the sensorimotor approach, it is *not* the case that mental states (experiential states) are logical constructions of actual and possible behavior states.

Said in another way, our explanation of sensory consciousness is not simply based on sensorimotor contingencies. Sensory consciousness arises, we say, when the person is currently making use of the fact that certain sensorimotor contingencies are being obeyed. For this to be the case, the brain must be doing more than just S-R. First, it must have abstracted from the sensorimotor contingencies categories that allow them to be classified into different sensory modalities and, within these, into different categories like red, blue, green. This is a form of concept formation, and is not just learning of behaviors, contrary to what **Van Gulick** suggests. Second, it must be making use of the *fact* that these sensorimotor contingencies are currently being obeyed. This is concept manipulation as might be done in an expert system or AI device. All this is therefore not behaviorism.

Block also criticizes us for being behaviorist. He writes: "O'Regan & Noë declare that the qualitative character of experience is constituted by the nature of the sensorimotor contingencies at play when we perceive." He characterizes sensorimotor contingencies as a "highly restricted set of input-output relations." The problem for us, he states, is that our view would appear to have two "clearly wrong" consequences: (1) that any two systems that share the highly restricted set of input-output relations are experientially the same; and (2) that any two systems that share experience must share the highly restricted set of input-output restrictions. Contrary to what Block thinks we claim, Block explains, "experience is a matter of what mediates between input and output, not input-output relations all by themselves."

However, **Block** has represented us incorrectly. Sensorimotor contingencies are laws describing input-output relations. But it is not sensorimotor contingencies, as such, that "constitute" the qualitative character of perceptual experience. It is *the perceiver's exercise of mastery of laws of sensorimotor contingency* that provides the basis for the character of experience. Our relation to our environment when we perceive is bodily and grabby and it is this fact, together with the fact that we implicitly understand the nature of this relation, that explains the qualitative nature of experience.

In light of this clarification of our position, consider, first, that this is hardly behaviorist reductionism. As said above, our view depends on the attribution of *knowledge* to the perceiver. Second, this means that we can accept Block's observation that experience *mediates* inputs and outputs and is not simply constituted by those relations. We disagree with Block, on the other hand, on the character of that mediation. For Block, the inputs *cause* experiences in us which in turn cause behavior (output). For us, in contrast, skillful activity (consisting of behavior and sensory stimulation) *is* the experience. We do not reduce the experience to the input-output relations themselves.

What of the two consequences of our view that **Block** gives? We reject (1). It is not the case that any two systems that share the same input-output relations will be experientially the same, unless, of course, they also agree in their skillful mastery of laws of sensorimotor contingency. They might not do so. Consider, for example, someone who is adapted to reversing goggles and someone who has just put them on. These two individuals will agree in their input-output relations but they will not agree in experience. Consequence (2), on the other hand, seems right: Same knowledge of sensorimotor contingencies, then same experience. It is worthwhile, though, to repeat a point made above in connection with **Clark & Toribio**. For two systems to have the same knowledge of sensorimotor contingencies *all the way down,* they will have to have bodies that are identical *all the way down* (at least in relevant respects). For only bodies that are alike in low-level detail can be functionally alike in the relevant ways.

R5. Dreaming, hearing, paralysis: Perceptual experience without action

Is action necessary for experience? Surely dreaming, meditation, tachistoscopic vision, hearing, pain, perception during paralysis, hallucinations such as phantom limbs, tinnitus, phosphenes, Penfield's experiments – all these are cases where people have perceptions without action being involved, and, as pointed out by **Blackmore**, **Humphrey**, **Niebur**, **Nusbaum et al.**, **O'Brien & Opie**, **Pylyshyn,** and **Virsu & Vanni**, they might pose problems for our approach. Further, **Fischer** gives an intriguing example where perception of the Zöllner illusion is more veridical *without* eye movements than with them, which would appear to contradict our theory. To respond to these objections, it is necessary to try to disentangle different strands of criticism. This is our aim in this section.

It is *not* our claim that action is necessary for experiencing. Our claim, rather, is that knowledge of the ways movements effect sensory stimulation is necessary for experience. It is not movement as such, but the consequences of potential movement that play a role in our view. For this reason there is nothing in our view that rules out *contemplative* seeing, or that would lead us to think that a paralyzed person would be unable to see (providing that the person had at some time previously had some kind of control over her visual input).

This is enough to make it clear how we can hear even when we hold our eyes and bodies absolutely still. As **Virsu & Vanni** note, through the course of its development, an organism will have integrated and abstracted laws of sensorimotor contingency particular to each sensory modality. At a later stage, when it is presented with a sensory input which is unambiguously linked to one or other such sensorimotor contingencies, it will implicitly "assume" that if it moved in the appropriate way, the changes in sensory input would be those that are normally associated with that type of stimulation. Thus, since normally input coming through the auditory nerve will change in certain ways when the head or body moves, when later, without moving, the organism is stimulated through the auditory nerve, the stimulation will be perceived as belonging to the auditory modality. This then provides an explanation of audition without head movements. Similar arguments can be made for brief visual stimulations, phosphenes, and stimulation of visual cortex à la Penfield, as well as for phantom limbs.

Niebur gives the example of a "three-dimensional lump of matter, like a mass of modelling clay, that is somehow moved by internal actuators in a complex, unpredictable way, without you having any possibility of influencing or predicting its motion and the forces it exerts on your hands (i.e., there is no 'mastery')." Niebur continues, "According to the claims of the target article, the lump should not be perceived since the perceiver does not interact with it in 'lawful' ways. This seems absurd; the lump will surely be perceived, and probably quite vividly so." First of all, we would not expect the subject to fail to perceive the lump just because its movements relative to the hands are actuated from within. Many laws of tactile-motor contingency would be in effect. For example, if you withdrew your hands you would no long receive stimulation. There is therefore no reason for doubting one would feel the lump. But let us ask: Would one also be able to feel its shape, to feel it as having such and such a shape? It might be very difficult to extract the relevant knowledge of the operative sensorimotor contingencies without actively exploring with your hands.

Pylyshyn writes

> while it is true that we often use our visual system to determine our actions, we also use it to find out what is in the world simply because we *want to know* . . . as we do when we watch TV or visit an art gallery or read a book . . . . Much of what we see guides our action only indirectly by changing what we believe and perhaps what we want.

There is nothing in this that we disagree with. **Pylyshyn**, like **Goodale**, seems to make the mistake of confusing the claim that seeing depends on capacities for action with the claim that all seeing is *for* action. Ours is not a theory about what vision is for, it is a theory about what vision is: it is a mode of interaction with the world drawing on knowledge of sensorimotor contingencies.

O'Brien & Opie and **Revonsuo** raise the question of dreams. Revonsuo believes that the phenomenon of dreaming shows that "the immediate causal conditions sufficient for bringing about the full range of subjective conscious experiences must reside inside the brain." This is so because when we dream we do not (cannot) move our bodies in interaction with the world. O'Brien & Opie make the same point, adding that "many theorists think it reasonable to surmise that dreams and hallucinations indicate something important about the nature of visual experience more generally, namely, that even 'veridical' experiences are constructed by the brain, and thus implicate internal representations."

There seem to be two issues here. First, whether our view can account for dreams and visual images. Second, whether neural activity is sufficient for such occurrences. We will discuss the second of these at greater length below in connection with our analysis of the role of brain in consciousness more generally. Here it suffices to point out that our view does not predict that it should be impossible to have visual experiences in the absence of movements. It would predict only that it would be impossible to have visual expriences in the absence of knowledge of sensorimotor contingencies. There is every reason to believe that dreamers possess knowledge of laws of sensorimotor contingency. It is also not part of our view to deny that the brain is not (in some sense at least) the seat of our knowledge of sensorimotor contingencies. We are, then, happy to accept the consequence that neural activity during dreaming is sufficient to produce the resulting experiences.

Although we are not expert in the psychology of dreaming, we are skeptical of **Revonsuo**'s claim that "the form of dream experience is identical to that of waking experience." In the article we noted that it seems to be a hallmark of dream-experiences that they are unstable with respect to detail. So, for example, as reported by the dream research of Stephen LaBerge (personal communication), in a dream the writing on a sign will be different every time you look at it. Without the world to act as a repository of information, details in the dream are in flux. In light of this we would predict (although we cannot now establish this) that there will be important systematic differences between the content of dreams and waking experiences, and that these differences will correspond to the fact that dreamers cannot look around and check how things are, they can only dream that they can do this.

In connection with this family of issues we would like to discuss briefly the suggestion of **Nusbaum et al.** that we should broaden our account to include not just motor behavior, but attentionally controlled exploration. In a similar vein, **Virsu & Vanni** suggest the concept of sensori-attentional contingencies. **Hochberg** (with examples of aperture viewing and interpretation of ambiguous 3D motions) similarly suggests that we should broaden our notion of sensorimotor contingencies to include not just coupling between action and sensory input, but also between different kinds of sensory input, as these are constrained by the nature of the physical world.

The cornerstone of the argument in our paper was the idea that we can close the explanatory gap by developing the consequences of the active, skill-based character of perceptual exploration. Experience arises not thanks to the existence of an internal representation, but thanks to the mastery and exercise of perceptual exploration. This may seem counterintuitive at first, but it enables us, we think, to explain experience without finding a special kind of physical mechanism to generate it. To the extent that the basis of our approach is that experiences are things we do, not things that happen in us, nothing prevents us from adopting **Nusbaum et al**.'s and **Virsu & Vanni**'s suggestion of using sensori-attentional contingencies instead of sensorimotor contingencies, since both are modes of action. Indeed, we would agree with Nusbaum et al. and Virsu & Vanni that insofar as pattern recognition and classification are concerned, the notions of sensori-attentional contingencies, or equivalently, hypothesis testing or matching of sensory input with internal knowledge, are certainly very plausible. Indeed we are convinced that such processes are precisely those that are involved in everyday pattern recognition, and for that reason, as noted by **Scholl & Simons**, at certain places in our paper we included flicks of attention as well as flicks of the eye among possible sensorimotor contingencies, even if there is no motor component.

A crucial feature of our theory, however, is the involvement of the body in experience. The peculiar, *sensory,* quality of our perceptual experience consists (in part) in the fact that movements of the body produce changes in our sensory stimulation. The content of *perception* is certainly in part the result of inferential processes, as **O'Brien & Opie** stress; but the quality of *experience,* is determined by senso*rimotor* contingencies and the bodiliness and grabbiness that goes with them.

R6. Does perceptual consciousness require representations in the head?

Our claims about representations provoked vehement criticism from many commentators.

Broackes argues that representations exist, but that they are fragmented, distributed, and multi-level. **Pani** argues that internal representations must be used in object recognition, and **Cohen** gives examples showing that the visual system extracts and categorizes information about the environment, and says this shows there are visual representations. **Tatler** and **De Graef et al.** give examples of information that is stored across eye saccades, showing the existence of an almost iconic internal representation. **Ryan & Cohen** and **Hardcastle** show how information acquired without awareness can influence later behavior, and say this shows there are internal representations. **Ansorge et al**.

remind us of an important body of data showing unconscious influences of visual information on motor responses. **Gallese & Keysers** cite mirror neurons as examples of internal representations that can be used not only to control actions but to perceive those performed by others. **Niebur** argues that internal neural responses such as oriented bar detectors are transformed versions of sensory input that constitute internal representations.

We are firmly convinced – and the data cited by the commentators provide proof – that the visual system stores information; and that this information – whether acquired consciously or unconsciously, whether iconic or abstract, whether local or distributed – influences the perceiver's behavior and mental states either directly or indirectly. If this is what is meant when it is insisted that perceiving depends on representations, then we do not deny that there are representations.

There is of course another sense in which our view relies on the existence of representations. Knowledge of the laws of sensorimotor contingency themselves must surely be represented. We readily grant this.

However, we reject two other distinct but related claims about the role of representations in perception and perceptual consciousness. The first of these concerns what Marr (1982) called "the computational problem" of vision, for example, what vision does, or what function the brain computes when it gives rise to vision. Marr's answer, roughly, is that vision is a process whereby the brain transforms one kind of representation into another, specifically, the retinal image into a representation of the three-dimensional scene. In the target article, we give two different kinds of reasons for rejecting Marr's representational account. First, we doubt that we enjoy perceptual experiences with the kind of content Marr's visual function is supposed to produce. As change blindness, inattentional blindness, and other experiments cited in the target article show, we do not have experiences that represent the environment in that way. Second, we doubt that we need representations of such detail in order to explain the sort of conscious experiences we do actually enjoy.

We can have a flawless, unified, continuous experience of the environment without having flawless, unified, continuous internal representations. The reason is that seeing is not contemplating an internal representation, but *doing something of a visual nature* with the information available to the brain. **Schlesinger's** interesting example of a representation-less reinforcement learning neural network that tracks objects *as though* it had representations of them, is a concrete instantiation of our idea. A consequence of the idea is also that there is no need to postulate filling-in mechanisms to fill in the blind spot, saccade-suppression mechanisms, and extra-retinal signals to compensate for eye movements, synchrony of neural firing to provide for binding, and so on. Indeed, when neurophysiologists find neurons that look like they are fulfilling such functions, we claim they cannot in fact be doing so. Consider a neuron that responds to a virtual contour. How can the firing of a particular neuron, by itself (that is, isolated from the rest of the brain), make me have the impression of a contour? It cannot. But connecting that neuron to other neurons would not appear to help either, because, after all, neural firing, no matter how complex or recurrent or synchronized, is just neural firing, not *sensation.* A related point concerns the mirror neurons referred to by **Gallese & Keysers.** Mirror neurons undoubtedly play a role in the processes involved when macaque monkeys recognize gestures. But the role they play cannot be the role of providing the sensation of seeing a gesture! Because, if the firing of mirror neurons provided the sensation of recognizing gestures, one would have to postulate some magical sensation-imbuing power to such neurons (or, to the networks that those neurons are connected to). So what do mirror neurons do? They presumably provide information to the brain circuits which control the multifarious things that macaque monkeys can potentially do when they act in response to gestures.

The second claim about representations that we reject concerns perceptual consciousness: that seeing could be a matter of having certain kinds of representations in the head. The existence of representations of the environment are neither sufficient nor necessary for seeing. That they are not sufficient is shown by consideration of the fact that, though people have very nice representations of the environment in the form of the images on their retinas, having the retinal image does not make people see. Seeing lies in the *making use* of the representation, not in the having of the representation. Because of this, the actual format of the representation (whether it's metric-preserving or distorted, iconic or abstract) is less important than whether, and how, that representation can be put to use in the sensorimotor activity of the organism. The brain may abstract information in the environment into a form that can be used in an open-ended range of applications, as **Van Gulick** says. But just *having* those abstract multi-purpose representations does not account for the what-it-is-like of seeing.

Of course, as **Tatler** and **De Graef et al**. point out, it is important to investigate the exact nature of information that is stored in the brain, and this can be done in the manner their very interesting experiments suggest. But finding iconic information in the low level, or middle-level, visual system does not explain why the world looks iconic to us.

An example of where our approach to the question of internal representations finds support is in the domain of motor control, as pointed out by **Smeets & Brenner**. If one takes the view that seeing a moving ball is making an internal representation of it, one is easily led to the misconception that this representation should resemble what a physicist would construct, that is, a representation where distance, position, speed, and time are linked by coherent physical laws. It then becomes problematic to understand how, as in the Duncker and waterfall illusions and in the flash lag effect, perceived position and perceived speed seem not to be coherently linked, or why size illusions affect lifting force but not grip aperture (cf. **Smeets & Brenner**). On the other hand, such findings are easier to comprehend under our view, according to which perception involves assimilating possibly independently acquired sensorimotor contingencies which have no necessary internal consistency**. Velichkovsky & Pannasch** also provide an example of an oculomotor distractor effect which may support our view. **Lacquaniti & Zago** provide further supporting data for the idea that different, more or less independent sensorimotor loops are used in perception: judgments of size and distance of moving objects constitute one type of visual perception, but another kind of visual perception, ruled by different sensorimotor loops, is involved in catching objects. Curiously, **Lacquaniti & Zago** take this to be contrary to our theory, when in fact it is exactly what we predict. Another example is provided by **Roberson et al**., who show that relative localization of auditory and visual stimuli depends on an observer's conceiving them as bound. This would be difficult to comprehend on a physicist-type view of the representation of the world. Still, in contradiction to our view, Roberson et al. mention neural connectivity between dorsal and ventral streams as possible substrates for binding: this may be the case, but then again, as we suggest, binding need not be instantiated in the brain at all.

Let us also address an interesting apparent paradox pointed out by **Tatler** and by **Scholl & Simons**. These commentators argue that the notion of sensorimotor contingency actually *requires* internal representations: after all, say these commentators, in order to register a change in sensory input when a body motion is made, an internal trace (representation!) of the initial and final state must be preserved in order to allow comparison. But the paradox is only apparent. We agree that the visual system stores information from moment to moment, and to some extent from saccade to saccade, and this is what is used to evaluate changes. But these changes are generally not available to awareness, and this stored information is not what is *seen*! Seeing, as we keep stressing, is *not* having an internal representation.

Finally, we would like to clarify one misunderstanding. *Pace* **Wright,** we do not claim that "all supporters of an internal presentation are committed to there being 'red neurons' in the brain." It isn't clear to us why **Wright** takes this to be our view. What we do believe is that certain arguments about the neural basis of experience seem to rely on mistakes just like the mistake of supposing that to see red there must be red neurons. As we explain in the target article, the very idea that there is a binding problem would seem to rest on just the assumption that, sensuous contents must indeed be *like* what controls their rise (to change slightly the phrase of Sellars's that Wright cites).

R7. The brain in consciousness

The role of the brain in perceptual consciousness is another topic on which we have drawn much criticism. Many commentators misunderstand us as denying that the brain is causally necessary for perceptual consciousness. **Lamme & Landman** ask whether anything other than neural events could explain consciousness and they propose that reentrant processes can do the job. **Bach-y-Rita & Hasse** complain that we seem to be throwing the brain out with the bath water, and suggest the importance of reentrant brain mechanisms as contributing to perceptual consciousness. **Revonsuo** says that consciousness is a real biological phenomenon in the brain, and notes that dreaming is proof that only the brain, with no input from outside, is necessary for perceptual awareness. **Rees & Frith** suggest that the superior parietal lobule is a brain locus that correlates consistently with awareness.

It seems probable that only a dualist could claim the brain plays no role in consciousness, and we are not dualists. Our claim, rather, is that many neuroscientists seem to be looking in the wrong direction for an account of the brain-basis of consciousness. We do not think that we will ever discover the Neural Correlates of Consciousness (NCC) – the neural system whose activity makes consciousness happen, or which *is* the event of consciousness itself. Our reason for this is straightforward: a visual experience is not an occurrence in the mind, that is produced by neural activity. Seeing is, in ways we explain, something we do, drawing on a range of sensorimotor (and also conceptual skills). Indeed, as we argue in the target article, we think this is what seeing actually seems like. Careful consideration reveals that when you see you do not encounter an inner something that is, so to speak, ongoing, buzzing, continuous. Your perceptual encounter is a state in which you have access and in which you know you have access. This knowledge makes it seem almost as though you are in contact with that to which you have access. But if there is no ongoing, buzzing, continuous state, then there is no ongoing, buzzing, continuous neural process that we need appeal to. (See Noë & Thompson, in press, and Chalmers 2000 for a critical discussion of the NCC research program.)

We can illustrate the point by way of a comparison. Consider what one might call the BCL: the biological correlate of life in humans. Clearly, a "contrastive analysis" of the kind Baars (1993) defends would show that the heart beat is an extremely reliable indicator of life. Thus, the heart beat is a BCL to the same extent as activity in the superior parietal lobule is a NCC. Having isolated this important correlate of life, the next step would then be to ask how it might contribute to *generating* life. But this would be an error. We should not think that the heart beat generates (or contributes to the generation) of life. What we mean by life is a complicated range of abilities (e.g., the ability to reproduce, respire, grow, eat, move, etc.). The beating heart is causally necessary for organisms like us to live. Neither the beating heart, nor any other physiological system or process, or even the sum of all them, generate life. Being "alive" is just what we say of systems that are made up in this way and that can do these sorts of things.

Our claim about consciousness is that consciousness stands to the brain as life stands to the heart. It reflects a simplistic account of what life is, or what consciousness is, to think that the brain produces consciousness or that the heart (or any other physiological processes) produce life.

What then is the correct way to approach neuroscience, in the context of our theory? We suggest that instead of seeking for the NCC, we should seek for the neural mechanisms that underlie each of the many capacities that underlie consciousness. We should not expect them to come together at any unifying locus in the brain. The consequences of this view have not been widely explored as yet. Indeed, **Bartolomeo & Chokron** note that much work could be done in exploring the neuropsychological evidence in favour of this view (and they discuss an interesting aspect of unilateral neglect related to the concept of grabbiness). Another interesting line of work in this respect is the research showing separate functions of dorsal and ventral systems in visual perception. **Goodale** notes that we may have got the exact relations between our theory and these two systems wrong, but certainly the fact that there should be separate systems underlying the different facets of visual consciousness is in favor of our approach. With respect to Goodale's criticism of the distinction between apparatus and object-related contingencies, our point was perhaps not clear in the target article: our idea is that a statistical device that analyzed input-output relations would first extract invariants that are related to the way the observer's body changes sensory input. Grasping an object, and properties of objects that influence that grasp, are part of this first level of statistics. All these are essentially coded in ego-centric coordinates. At the second level are properties of objects that are invariant with respect to the observer's body, for example: size, color, shape, as considered independently of the observer's position, in other words, in object-centered coordinates. What this means, as found in Goodale's example, is that someone lacking this stage would be able to grasp, but would not be able to describe the shape of an object. It's worth mentioning that Goodale's view stumbles on the problem of the explanatory gap. Just what is it, one might ask, about neural activity in the ventral sream that gives rise to visual experience?

R8. Coherent theory or untestable mish-mash of old ideas?

Scholl & Simons believe that our approach is just a *bric a brac* of old ideas, combined to yield an untestable mess.

As concerns our relation to earlier researchers, **Scholl & Simons**, as well as **Kim** (who also provides evidence in favor of our theory), note the debt we owe to Gibson. Similarity to Gibson in some respects is also noticed by **Pylyshyn** (who notes an important *dis*similarity as well), **Velichkovsky & Pannasch**, and is suggested by **O'Brien & Opie** (in their citation of Fodor and Pylyshyn's well-known criticism of the ecological approach: Fodor & Pylyshyn 1981). Velichkovsky & Pannasch say our work reminds them of the Russian School of the 1960s. No commentators mentioned Heidegger, Husserl, Merleau-Ponty, or Poincaré, who are other giants upon whose shoulders we stand, although one unpublished commentator also mentioned Bergson.

Our relation to Gibson. Gibson challenged traditional ideas about the information available to the perceiver in visual perception. He argued that the information needed for vision is available in the optic flow and in invariants of the flow under body motions. He rejected the idea that the only information available for vision is that which is available at the retina. We fully endorse Gibson's viewpoint. The focus of our investigation is totally different, however. Our target is the explanation of perceptual *consciousness* – why is there perceptual experience? why are some experiences distinctively *visual* whereas others are distinctively *tactile*? Our proposal is that we should think of sensory experiences as active – as things we do rather than as things that happen in us. In adopting this view we invoke the role of action and the importance of extracting invariants, and so we are indebted to Gibson. But we harness these ideas for quite different explanatory and theoretical purposes.

In other words, whereas Gibson stresses the use of sensorimotor invariants as sources of information, we are stressing the idea that sensorimotor invariants are part of what *constitute* sensations and perceptual content. We show that Gibson's idea can go farther than Gibson pushed it.

Scholl & Simons suggest that one of our differences with Gibson might be that we place more emphasis on those particular sensorimotor laws that are related to the observer's peculiar, idiosyncratic sensory apparatus. This is both right and wrong. We think the particular idiosyncratic laws peculiar to each human individual are one part of a heirarchy of sensorimotor contingencies. This lowest level defines the ineffable what-it-is-likeness of red, say, for me, different from you. But at a higher level of abstraction, there are laws like the laws of how light from surfaces is affected when you tilt them, which are common to most people and define the invariant qualities of red. Perhaps this is more similar to Gibson's affordances, and less dependent on individuals' apparatus.

As concerns the coherence of the theory, **Scholl & Simons** are right to point out that what we call sensorimotor theory is not composed of one single idea. We obviously were not clear enough in our target article on how the different ideas fit together and on where lies their common motivation. Let us first address the relation between "the world as an outside memory" idea and the notion of sensorimotor contingency.

The sensorimotor approach and the idea of the world as outside memory. Knowledge of sensorimotor contingencies explains the qualitative character of perceptual experience. We encounter red, as opposed to green, or as opposed to no color, because of the ways our sensory stimulation depends on our movements and also on movements of the colored surface. We experience *red* because we take our sensory stimulation to be governed by the relevant laws. The idea is extended to perception (as opposed to merely "sensation") as follows: seeing a bottle is knowing how moving the bottle affects sensory input. Only part of the bottle is at any moment being explored. It serves as an outside entity which is immediately available for exploration, like a memory is immediately available for recovery. Hence the notion of "world as an outside memory." The idea explains the feeling of richness we get even though at any moment we're only in sensory contact with a small part of the stimulus. This is the theoretical link between the two concepts of knowledge of laws of sensorimotor contingency and world as an outside memory. They form a unified structure in our theory.

The relation to change blindness. **Scholl & Simons** accept that change blindness was motivated by the "world as outside memory" idea, but mention that other, earlier experiments preceded the recent change blindness literature, and that these had a different motivation. In fact, the work of McConkie on saccade contingent changes was contemporaneous with a number of similar studies which the first author (O'Regan) was conducting involving changes during saccades. These studies were concerned with the question of trans-saccadic fusion and the extra-retinal signal, that is, the question of how successive views of the environment are brought together to give a coherent representation (O'Regan 1984; O'Regan & Levy-Schoen 1983). It was the results of these experiments, which led the first author to the notion of world as outside memory. In arriving at this idea the first author was most helped by MacKay. On the other hand, Brooks (1991) and, particularly Stroud (1955), though cited by Scholl & Simons, actually mention the concept only very much in passing. Minsky (1988) does indeed make a similar point, as we noted in the target article.

With respect to auditory perception let us note parenthetically here, in relation to **Isel**'s commentary, that failure to find change deafness is not contrary to our theory – change blindness is also not ubiquitous: it only occurs with coincident visual transients, and mainly in cases where changes concern marginal interest items.

Scholl & Simons question whether change blindess actually provides support for the idea of the world as an outside memory. Scholl & Simons correctly point out that other possibilities are consistent with the phenomenon, that is, that change blindness does not logically entail the world-as-an-outside-memory view. **Lamme & Landman** actually suggest one such alternative. This is of course no argument against our explanatory proposal, however. In general, phenomena will admit of many possible explanations. The advantage of one explanation over another lies in the way it fits with other theoretical constructs of a theory. We offer an account of perceptual consciousness in terms of knowledge of sensorimotor contingencies and the idea of the world as outside memory that explains a broad range of phenomena such as change blindness, inattentional blindness, sensory substitution, experiments with inverting goggles, the nature of sensory modalities, and so on (as discussed in the target article). Scholl & Simons criticize the theory because they say these phenomena are more or less independent of one another. It's true that they *could* be independent, but in fact they are united here by one underlying idea, namely, that when taken together with the notion of "feel" as a thing people *do,* they allow the explanatory gap to be bridged.

Scholl & Simons also question whether the theory is testable. Change blindness was one prediction made from the idea of the world as an outside memory (O'Regan 1992). As said above, although change blindness is compatible with other frameworks, it is striking that no other framework predicted change blindness. Change blindness only became an active paradigm *after* the first change blindness experiments with the flicker and mudsplash techniques were performed. The McConkie work (e.g., McConkie & Zola 1979) that Scholl & Simons referred to was done using eye saccades, because McConkie's prediction concerned the problem of trans-saccadic fusion, and not the more general problem of what the sensation of seeing is. The work by Phillips (1974) was motivated by the problem of understanding iconic memory, and was ignored until it was resuscitated by the change blindness literature. We therefore consider change blindness, even though it can be explained in other ways, as an instance of how the theory made interesting predictions. Indeed, one other researcher did predict change blindness, and it was the philosopher Dennett (1991), with an idea very similar to ours, namely, that there is no time or place in the brain where consciousness "happens."

The "armchair" experiment with colour we mentioned in section 5.8 of the target article is another counterintuitive prediction which we are currently testing, and which has met with some success (O'Regan et al. 2001). Different kinds of sensory substitution and the possibility of creating new, previously unfelt sensations, is another avenue we are exploring.

Blackmore, who is certainly the commentator who best understood the spirit of our approach, proposes three additional, fascinating experiments which would also be ways of confirming the theory because they are so counterintuitive. What she calls "scrambled vision" is something we have actually already attempted (in collaboration with C. Tyler), but, regrettably, at present without success. Evidence that it might nevertheless work comes from the well-known fact that people who develop scotomas very quickly come to no longer "see" them. On the other hand, people with age-related macular degeneration suffer another kind of scrambled vision, to the extent that the buckling of their retinas has the effect of making straight lines look wiggly. Our prediction would be that practise should iron out the wiggles, provided they don't change over time.

What Blackmore calls "manual vision" is a very intriguing proposal and bears on the question of where people locate a sensation. There are modalities, like vision, where qualities are located in the outside object. There are modalities like touch, where they are located in the limb where contact occurs. There are modalities in-between, like smell and hearing, where there is a sense in which the quality is located in the object outside, and a sense in which people say they experience the stimulation at the locus of the detector, or even at other locations. An example is when you hear a sound inside your head when you listen to music through stereo headphones. As Blackmore rightly says, according to our theory the locus of sensation will depend on the nature of the sensorimotor contingencies, and by changing these laws, it should be possible to change the locus of perception. We are indeed embarking on experiments very similar to those proposed by Blackmore to test this. A suggestion that they will work comes from the rubber arm experiment of Botvinick & Cohen (1998) cited in our target article, and the related work of Ramachandran & Blakeslee (1998) on phantom limbs, as well as Bach-y-Rita (1983) (cf. also Sampaio et al.'s 2001 work on sensory substitution).

What Blackmore calls "blinded vision" was, of course, tested to some extent by Held and Hein (1963) in their famous work on kittens in the kitten carousel. Each kitten received the same visual stimulation, but only one kitten received the stimulation as a result of self-produced movement. As predicted by our approach, only the active kitten subsequently displayed normal visually guided behavior. In humans, similar suggestions as to the importance of action for acquiring sensory proficiency derive from the finding that severe strabismus seems related to amblyopia. However, Blackmore's point seems to be that she thinks that this kind of finding should be observable not just during development, but also at a shorter time scale *in the mature sensory system.* In a certain sense we agree that our approach suggests that since perception is *constituted* by mastery of sensorimotor contingencies, the brain must be continually updating and analysing the input-output statistics and making use of them to categorize outside events. This suggests that adaptation to re-arrangement of sensorimotor contingencies could be much faster than what one would expect under a more traditional view, according to which such adaptation is a matter of brain "plasticity," occurring fairly slowly in response to environmental or body changes, as during maturation, for example. The question of course is, how much faster? Such experiments need to be done, but lacking willing subjects at present, we have not been able to embark upon them. Meanwhile, we note that the relative speed with which sensory substitution seems to be acquired suggests that adaptation is indeed faster than might be expected from a traditional theory.

R9. Conclusion

The most important claim in the target article was that the sensorimotor approach allows us to address the problem of the explanatory gap: that is, the problem of explaining perception, consciousness, and qualia in terms of physical and functional properties of perceptual systems. While the target article left many of our commentators unconvinced, we think that in our response we have provided a more convincing argument. Our case has been strengthened by introducing two concepts which, though incipient in the target article, were not properly exploited there. These are the concepts of bodiliness and grabbiness. Bodiliness and grabbiness are physically measurable characteristics of perceptual systems which, when combined with the notion of sensorimotor contingency, explain why sensation has a "feel," and what that feel is like in comparison to other mental states which have little or no feel. We suggest that in this way we have cast the first steps of what might be called an "analytical phenomenology" (or perhaps a "heterophenomenology"?); that is, a scientific account of the experienced qualitative nature of sensations within a given sensory modality, as well as the principles that distinguish sensations across different modalities.

Many commentators misunderstood our claims about internal representations and the role of the brain in consciousness. We hope to have shown in our reply that we are not so extravagant as to claim that the brain contains no information, or that it serves no purpose in cognition. On the other hand, we hope to have shown how making a shift in the way we think about representations and the role of the brain leads to new ways of understanding the nature of phenomenal consciousness. The shift we advocate consists in suggesting that experience does not involve having an internal representation, but instead involves *making use of certain capacities* to interact with the environment. Though counter-intuitive at first sight, this approach, in addition to dealing satisfactorily with phenomenology, sheds a new light on previously unconnected phenomena in experimental psychology, and makes empirically testable predictions.

NOTE

1. Malcolm appears to have been the first person to use this term in print, but Rosenthal used the term first in papers written and presented but not published in the 1970s. Rosenthal's usage is the main source of the idea in contemporary discussions.

References

Letters "a" and "r" appearing before authors' initials refer to target article and response, respectively.

Abeles, M. & Prut, Y. (1996) Spatio-temporal firing patterns in the frontal cortex of behaving monkeys. *Journal of Physiology (Paris)* 90(3–4):249–50. [aJKO]

Alderson, G. J. K., Sully, D. J. & Sully, H. G. (1974) An operational analysis of a one-handed catching task using high speed photography. *Journal of Motor Behavior* 6:217–26. [FL]

Aloimonos, J., Weiss, I. & Bandyopadhyay, A. (1988) Active vision. *International Journal of Computer Vision* 2:333–56. [N-GK]

Aloimonos, Y. E. (1992) Purposive, qualitative, active vision. *Computer Vision, Graphics and Image Processing: Image Understanding* 56(1). [Special issue, ed. Y. E. Aloimonos.]. [aJKO]

Alroy, D. (1991) Inner light. *Synthese* 104(1):147–60. [EW]

Althoff, R. R. & Cohen, N. J. (1999) Eye-movement-based memory effect: A reprocessing effect in face perception. *Journal of Experimental Psychology: Learning, Memory, and Cognition* 25(4):997–1010. [JDR]

Anderson, S. J., Mullen, K. T. & Hess, R. F. (1991) Human peripheral spatial resolution for achromatic and chromatic stimuli: Limits imposed by optical and retinal factors. *Journal of Physiology (London)* 442:47–64. [aJKO]

Andersson, R. L. (1988) *Robot ping-pong player.* MIT Press. [AC]

Ansorge, U., Klotz, W. & Neumann, O. (1998) Manual and verbal responses to completely masked (unreportable) stimuli: Exploring some conditions for the metacontrast dissociation. *Perception* 27:1177–89. [UA]

Ansorge, U. & Neumann, O. (2001) Intentions determine the effect of nonconsciously registered visual information: Evidence for direct parameter specification in the metacontrast dissociation. In: *Proceedings of the AISB 2001 Symposium on Nonconscious Intelligence: From natural to artificial.* The Society for the Study of Artificial Intelligence and the Simulation of Behaviour. [UA]

Apkarian, P. A. (1983) Visual training after long term deprivation: A case report. *International Journal of Neuroscience* 19(1–4):65–83. [aJKO]

Archambault, A., O'Donnell, C. & Schyns, P. G. (1999) Blind to object changes: When learning the same object at different levels of categorization modifies its perception. *Psychological Science* 10:249–55. [JRP]

Arend, L. E., Jr. (1973) Spatial differential and integral operations in human vision: Implications of stabilized retinal image fading. *Psychological Review* 80(5):374–95. [aJKO]

Arias, C. (1996) L'écholocation humaine chez les handicapés visuels. *L'Année Psychologique* 96:703–21. [aJKO]

Assad, J. A. & Maunsell, J. H. R. (1995) Neuronal correlates of inferred motion in primate posterior parietal cortex. *Nature* 373:518–21. [VAFL]

Atkinson, J., Campbell, F. W. & Francis, M. R. (1976) The magic number 4 +/− 0: A new look at visual numerosity judgements. *Perception* 5(3):327–34. [aJKO]

Bachman, T. (2000) *Microgenetic approach to the conscious mind.* John Benjamins. [PByR]

Bach-y-Rita, P. (1972) *Brain mechanisms in sensory substitution.* Academic Press. [aJKO]

(1983) Tactile vision substitution: Past and future. *International Journal of Neuroscience* 19(1–4):29–36. [aJKO]

(1984) The relationship between motor processes and cognition in tactile vision substitution. In: *Cognition and motor processes,* ed. A. F. Sanders & W. Prinz. Springer. [aJKO]

(1996) Substitution sensorielle et qualia. In: *Perception et Intermodalité,* ed. J. Proust. Presses Universitaires de France. [aJKO]

Bach-y-Rita, P., Collins, C. C., Saunders, S. A., White, B. & Scadden, L. (1969) Vision substitution by tactile image projection. *Nature* 221:963–64. [PByR]

Bach-y-Rita, P., Tyler, M. E. & Kaczmarek, K. A. (in press) Seeing with the brain. *International Journal of Human-Computer Interaction.* [PByR]

Baillargeon, R. (1986) Representing the existence and the location of hidden objects: Object permanence in 6- and 8-month-old infants. *Cognition* 23:21–41. [MS]

(1999) Young infants' expectations about hidden objects: A reply to three challenges. *Developmental Science* 2:115–32. [MS]

Bajcsy, R. (1988) Active perception. *Proceedings of the IEEE* 76:996–1005. [aJKO]

Balibar, F. (1992) *Einstein 1905. De L'éther aux quanta.* Presses Universitaires de France. [aJKO]

Ballard, D. H. (1991) Animate vision. *Artificial Intelligence* 48:57–86. [aJKO]

(1996) On the function of visual representation. In: *Perception,* ed. K. Akins. Oxford University Press. [N-GK]

Ballard, D. H., Hayhoe, M. M., Pook, P. K. & Rao, R. P. N. (1997) Deictic codes for the embodiment of cognition. *Behavioral and Brain Sciences* 20(4):723–67. [aJKO, MS]

Baron-Cohen, S. & Harrison, J. (1996) *Synesthesia: Classic and contemporary readings.* Blackwell. [aJKO]

Bartlett, F. C. (1932) *Remembering: A study in experimental and social psychology.* Cambridge University Press. [JDR]

Bartolomeo, P. & Chokron, S. (1999) Left unilateral neglect or right hyperattention? *Neurology* 53:2023–27. [PB]

Bartolomeo, P., Chokron, S. & Siéroff, E. (1999) Facilitation instead of inhibition for repeated right-sided events in left neglect. *NeuroReport* 10(16):3353–57. [PB]

Bartolomeo, P., D'Erme, P. & Gainotti, G. (1994) The relationship between visuospatial and representational neglect. *Neurology* 44:1710–14. [PB]

Bartolomeo, P., Siéroff, E., Decaix, C. & Chokron, S. (2001) Modulating the attentional bias in unilateral neglect: The effects of the strategic set. *Experimental Brain Research* 137(3/4):424–31. [PB]

Bauby, J.-D. (1997) *The diving bell and the butterfly,* trans. J. Leggatt. Fourth Estate. [GR]

Bechara, A., Damasio, H., Tranel, K. & Damasio, A. R. (1997) Deciding advantageously before knowing the advantageous strategy. *Science* 275:1293–95. [VGH]

Beck, D., Rees, G., Frith, C. D. & Lavie, N. (2001) Neural correlates of change detection and change blindness. *Nature Neuroscience* 4(6):645–50. [GR]

Becker, M. W., Pashler, H. & Anstis, S. M. (2000) The role of iconic memory in change-detection tasks. *Perception* 29(3):273–86. [PDG, VAFL, BWT]

Beckers, G. & Homberg, V. (1992) Cerebral visual motion blindness: Transitory akinetopsia induced by transcranial magnetic stimulation of human area V5. *Proceedings of the Royal Society of London B: Biological Sciences* 249(1325):173–78. [GR]

Bedford, F. L. (1995) Constraints on perceptual learning: Objects and dimensions. *Cognition* 54(3):253–97. [aJKO]
Benson, D. F. & Greenberg, J. P. (1969) Visual form agnosia: A specific deficit in visual discrimination. *Archives of Neurology* 20:82–89. [aJKO]
Berthoz, A. (1997) *Le sens du mouvement.* Odile Jacob. [aJKO]
Binder, J. R., Frost, J. A., Hammeke, T. A., Bellgowan, P. S. F., Springer, J. A., Kaufman, J. N. & Possing, E. T. (2000) Human temporal lobe activation by speech and nonspeech sounds. *Cerebral Cortex* 10:512–28. [HCN]
Bisiach, E. & Luzzatti, C. (1978) Unilateral neglect of representational space. *Cortex* 14:129–33. [PB]
Bisiach, E., Pizzamiglio, L., Nico, D. & Antonucci, G. (1996) Beyond unilateral neglect. *Brain* 119:851–57. [PB]
Block, N. (1981) *Imagery.* MIT Press. [GO]
(1995a) How many concepts of consciousness? *Behavioral and Brain Sciences* 18(2):272–84. [NB]
(1995b) On a confusion about a function of consciousness. *Behavioral and Brain Sciences* 18(2):227–47. [aJKO]
(1995c) The mind as the software of the brain. In: *An invitation to cognitive science,* ed. D. Osherson, L. Gleitman, S. Kosslyn, E. Smith & S. Sternberg. MIT Press. [NB]
(1996) How can we find the neural correlate of consciousness? *Trends in Neurosciences* 19:456–59. [VAFL]
Bogartz, R. S., Shinksey, J. L. & Schilling, T. H. (2000) Object permanence in five-and-a-half-month-old infants? *Infancy* 1:403–28. [MS]
Bone, R. A., Landrum, J. T. & Cains, A. (1992) Optical density spectra of the macular pigment in vivo and in vitro. *Vision Research* 32(1):105–10. [aJKO]
Botvinick, M. & Cohen, J. (1998) Rubber hands "feel" touch that eyes see [letter]. *Nature* 391(6669):756. [aJKO]
Bower, T. G. R. (1977) Blind babies see with their ears. *New Scientist* 73:255–57. [aJKO]
(1979) *Human development.* Freeman. [aJKO]
Braddon-Mitchell, D. & Jackson, F. (1996) *Philosophy of mind and cognition.* Blackwell. [NB]
Brecht, M., Singer, W. & Engel, A. K. (1998) Correlation analysis of corticotectal interactions in the cat visual system. *Journal of Neurophysiology* 79(5):2394–407. [aJKO]
Breitmeyer, B. G. & Ganz, L. (1976) Implications of sustained and transient channels for theories of visual pattern masking, saccadic suppression, and information processing. *Psychological Review* 83(1):1–36. [aJKO]
Brenner, E. & Smeets, J. B. J. (1996) Size illusion influences how we lift but not how we grasp an object. *Experimental Brain Research* 111:473–76. [JBJS]
(2000) Motion extrapolation is not responsible for the flash-lag effect. *Vision Research* 40:1645–48. [JBJS]
Bridgeman, B. (1992) Conscious vs. unconscious processes. The case of vision. *Theory and Psychology* 2:73–88. [UA]
(1995) Extraretinal signals in visual orientation. In: *Handbook of perception and action, vol. 1: Perception,* ed. W. Prinz & B. Bridgeman. Academic Press. [aJKO]
Bridgeman, B. & Stark, L. (1991) Ocular proprioception and efference copy in registering visual direction. *Vision Research* 31(11):1903–13. [aJKO]
Bridgeman, B., Van der Heijden, A. & Velichkovsky, B. M. (1994) A theory of spatial stability across saccadic eye movements. *Behavioral and Brain Sciences* 17(2):247–92. [BMV]
Broackes, J. (1992) The autonomy of colour. In: *Reduction, explanation, and realism,* ed. K. Lennon & D. Charles. Oxford University Press. [aJKO]
Brooks, R. (1987) Autonomous mobile robots. In: *AI in the 1980s and beyond,* ed. W. E. L. Grimson & R. S. Patil. MIT Press. [aJKO]
(1991) Intelligence without representation. *Artificial Intelligence* 47:139–59. [arJKO, BJS]
Brown, R. (1958) *Words and things.* Macmillan. [JRP]
Burr, D. C., Morrone, M. C. & Ross, J. (1994) Selective suppression of the magnocellular visual pathway during saccadic eye movements. *Nature* 371:511–13. [aJKO]
Burton, M. W., Small, S. L. & Blumstein, S. E. (2000) The role of segmentation in phonological processing: An fMRI investigation. *Journal of Cognitive Neuroscience* 12:679–90. [HCN]
Carlson-Radvansky, L. A. (1999) Memory for relational information across eye movements. *Perception and Psychophysics* 61:919–34. [PDG]
Carrasco, M. & Frieder, K. S. (1997) Cortical magnification neutralizes the eccentricity effect in visual search. *Vision Research* 37:63–82. [VV]
Case, T. (1888) *Physical realism, being an analytical philosophy from the physical objects of science to the physical data of sense.* Longmans Green. [EW]
Castelo-Branco, M., Neuenschwander, S. & Singer, W. (1998) Synchronization of visual responses between the cortex, lateral geniculate nucleus, and retina in the anesthetized cat. *Journal of Neuroscience* 18(16):6395–410. [aJKO]
Chalmers, D. J. (1996a) *The conscious mind: In search of a fundamental theory.* Oxford University Press. [RM, KO, aJKO]
(1996b) *On the search for the neural correlate of consciousness.* Paper presented at the Tucson II Conference: Towards a Science of Consciousness, Tucson, Arizona, 1996. [aJKO]
Chelazze, L., Miller, E. K., Duncan, J. & Desimone, R. (1983) A neural basis for visual search in inferior temporal cortex. *Nature* 363:345–47. [aJKO]
Chokron, S., Bartolomeo, P., Perenin, M. T., Helft, G. & Imbert, M. (1998) Scanning direction and line bisection: A study of normal subjects and unilateral neglect patients with opposite reading habits. *Cognitive Brain Research* 7(2):173–78. [PB]
Chokron, S., Bernard, J. M. & Imbert, M. (1997) Length representation in normal and neglect subjects with opposite reading habits studied through a line extension task. *Cortex* 33:47–64. [PB]
Chokron, S. & De Agostini, M. (2000) Reading habits influence aesthetic preference. *Cognitive Brain Research* 10(1–2):45–49. [PB]
Chokron, S. & Imbert, M. (1993) Influence of reading habits on line bisection. *Cognitive Brain Research* 1:219–22. [PB]
Chun, M. M. & Jiang, Y. (1998) Contextual cueing: Implicit learning and memory of visual context guides spatial attention. *Cognitive Psychology* 36(1):28–71. [aJKO, JDR]
Chun, M. M. & Nakayama, K. (2000) On the functional role of implicit visual memory for the adaptive deployment of attention across scenes. *Visual Cognition* 7(1/2/3):65–82. [aJKO]
Clancey, W. J. (1997) *Situation cognition: On human knowledge and computer representations.* Cambridge University Press. [aJKO]
Clark, A. (forthcoming) Visual experience and motor action: Are the bonds too tight? *Philosophical Review.* [AC]
Cogan, A. I. (1995) Vision comes to mind. *Perception* 24(7):811–26. [aJKO]
Cohen, L. G., Weeks, R. A., Sadato, N., Celnik, P., Ishii, K. & Hallett, M. (1999) Period of susceptibility for cross-modal plasticity in the blind. *Annals of Neurology* 45(4):451–60. [aJKO]
Colby, C. L., Duhamel, J. R. & Goldberg, M. E. (1996) Visual, presaccadic, and cognitive activation of single neurons in monkey lateral intraparietal area. *Journal of Neurophysiology* 76(5):2841–52. [aJKO]
Cole, D. (1991) Functionalism and inverted spectra. In: *Epistemology and cognition: Studies in cognitive systems, vol. 6,* ed. J. H. Fetzer. Kluwer Academic. [aJKO]
Coletta, N. J. & Williams, D. R. (1987) Psychophysical estimate of extrafoveal cone spacing. *Journal of the Optical Society of America [A]* 4(8):1503–13. [aJKO]
Collins, A. W. (1967) The epistemological status of the concept of perception. *Philosophical Review* 76:436–59. [EW]
Cornilleau-Peres, V. & Droulez, J. (1994) The visual perception of three-dimensional shape from self-motion and object-motion. *Vision Research* 34(18):2331–36. [aJKO]
Cotterill, R. M. J. (1995) On the unity of conscious experience. *Journal of Consciousness Studies* 2:290–312. [aJKO]
(1997) On the mechanism of consciousness. *Journal of Consciousness Studies* 4:231–47. [aJKO]
Cowan, N. (1988) Evolving conceptions of memory storage, selective attention, and their mutual constraints within the human information processing system. *Psychological Bulletin* 104:163–91. [VAFL]
Crick, F. & Koch, C. (1990) Toward a neurobiological theory of consciousness. *Seminars in the Neurosciences* 2:263–75. [aJKO]
(1995) Are we aware of neural activity in primary visual cortex? *Nature* 375:121–23. [aJKO]
(1998) Consciousness and neuroscience. *Cerebral Cortex* 8:97–107. [VAFL, aJKO]
Cytowic, R. E. & Wood, F. B. (1982) Synesthesia. I. A review of major theories and their brain basis. *Brain and Cognition* 1(1):23–35. [aJKO]
D'Zmura, M. & Lennie, P. (1986) Mechanisms of color constancy. *Journal of the Optical Society of America* 3(10):1662–72. [aJKO]
Dallenbach, K. M., Supa, M. & Cotzin, M. (1944) "Facial vision" the perception of obstacles by the blind. *American Journal of Psychology* 57:133–83. [aJKO]
De Graef, P. & Verfaillie, K. (2001a) Transsaccadic memory and on-line scene representations. Paper presented at the 11th European Conference on Eye Movements, Turku, Finland, August 2001. [PDG, BWT]
De Graef, P. & Verfaillie, K., eds. (2001b) Special Issue on Transaccadic Object Perception. *Psychologica Belgica* 41(1/2). [PDG]
Dehaene, S., Naccache, L., Cohen, L., Bihan, D. L., Mangin, J. F., Poline, J. B. & Riviere, D. (2001) Cerebral mechanisms of word masking and unconscious repetition priming. *Nature Neuroscience* 4(7):752–58. [GR]
Dehaene, S., Naccache, L., Le Clec'H, G., Koechlin, E., Mueller, M., Dehaene-Lambertz, G., van de Moortele, P. & Le Bihan, D. (1998) Imaging unconscious semantic priming. *Nature* 395:597–600. [UA]
Dennett, D. C. (1969) *Content and consciousness.* Routledge & Kegan Paul. [aJKO]
(1978) *Brainstorms.* MIT Press. [aJKO]
(1987) *The intentional stance.* MIT Press. [aJKO]
(1991) *Consciousness explained.* Little, Brown. [SJB, DCD, MK, KO, arJKO, BJS]

(1995) The path not taken. *Behavioral and Brain Sciences* 18(2):252–53. [aJKO]

Dennett, D. C. & Kinsbourne, M. (1992) Time and the observer: The where and when of consciousness in the brain. *Behavioral and Brain Sciences* 15:183–247. [aJKO]

Desimone, R. & Duncan, J. (1995) Neural mechanisms of selective visual attention. *Annual Review of Neuroscience* 18:193–220. [VAFL]

Deubel, H., Bridgeman, B. & Schneider, W. X. (1998) Immediate post-saccadic information mediates space constancy. *Vision Research* 38:3147–59. [PDG]

Deubel, H., Schneider, W. X. & Bridgeman, B. (1996) Postsaccadic target blanking prevents saccadic suppression of image displacement. *Vision Research* 36:985–96. [PDG]

De Weerd, P., Gattass, R., Desimone, R. & Ungerleider, L. G. (1995) Responses of cells in monkey visual cortex during perceptual filling-in of an artificial scotoma. *Nature* 377(6551):731–34. [aJKO]

De Yoe, E. A. & van Essen, D. C. (1988) Concurrent processing streams in monkey visual cortex. *Trends in Neuroscience* 11:219–26. [aJKO]

Dijkstra, T. M., Cornilleau-Peres, V., Gielen, C. C. & Droulez, J. (1995) Perception of three-dimensional shape from ego- and object-motion: Comparison between small- and large-field stimuli. *Vision Research* 35(4):453–62. [aJKO]

Di Lollo, V. Enns, J. T. & Rensnik, R. A. (2000) Competition for consciousness among visual events: The psychophysics of reentrant processes. *Journal of Experimental Psychology: General* 129:481–507. [PByR]

Ditchburn, R. W. (1973) *Eye-movements and visual perception.* Clarendon Press. [aJKO]

Dodwell, P. C. (2000) *Brave new mind: A thoughtful inquiry into the nature and meaning of mental life.* Oxford University Press. [PByR]

Dolezal, H. (1982) *Living in a world transformed.* Academic Press. [aJKO]

Duhamel, J. R., Colby, C. L. & Goldberg, M. E. (1992) The updating of the representation of visual space in parietal cortex by intended eye movements. *Science* 255(5040):90–92. [aJKO]

Dulany, D. E. (1997) Consciousness in the explicit (deliberative) and implicit (evocative). In: *Scientific approaches to consciousness,* ed. J. D. Cohen & J. W. Schooler. Erlbaum. [UA]

Durgin, F. H., Tripathy, S. P. & Levi, D. M. (1995) On the filling in of the visual blind spot: Some rules of thumb. *Perception* 24(7):827–40. [aJKO]

Easton, R. D. (1992) Inherent problems of attempts to apply sonar and vibrotactile sensory aid technology to the perceptual needs of the blind. *Optometry and Vision Science* 69(1):3–14. [aJKO]

Edelman, G. M. (1987) *Neural Darwinism: The theory of neuronal group selection.* Basic Books. [RM]

(1989) *The remembered present.* Basic Books. [aJKO]

Edelman, G. M. & Tononi, G. (2000) *A universe of consciousness: How matter becomes imagination.* Allen Lane. [RM]

Eimer, M. & Schlaghecken, F. (1998) Effects of masked stimuli on motor activation: Behavioral and electrophysiological evidence. *Journal of Experimental Psychology: Human Perception and Performance* 24:1737–47. [UA]

Eriksen, C. W. (1960) Discrimination and learning without awareness: A methodological survey and evaluation. *Psychological Review* 67:279–300. [UA]

Farah, M. J. (1989) The neural basis of mental imagery. *Trends in Neurosciences* 12(10):395–99. [aJKO]

ffytche, D. H., Howard, R. J., Brammer, M. J., David, A., Woodruff, P. & Williams, S. (1998) The anatomy of conscious vision: An fMRI study of visual hallucinations. *Nature Neuroscience* 1(8):738–42. [GR]

Fischer, B., daPos, O. & Stürzel, F. (2001a) The Z-illusion: A new geometrical illusion disappearing by fixation. (submitted). [BF]

(2001b) Disillusions. (submitted). [BF]

Fischer, B. & Weber, H. (1992) Characteristics of "anti" saccades in man. *Experimental Brain Research* 89:415–24. [BF]

(1996) Effects of precues on error rate and reaction times of antisaccades in human subjects. *Experimental Brain Research* 109:507–12. [BF]

Fisher, E., Haines, R. F. & Price, T. A. (1980) *Head-up transition behavior of pilots with and without head-up display in simulated low-visibility approaches.* (Technical Paper). NASA. [FI, aJKO]

Fishman, M. C. & Michael, C. R. (1973) Integration of auditory information in cat's visual cortex. *Vision Research* 13:1415. [aJKO]

Fodor, J. & Pylyshyn, Z. (1981) How direct is visual perception? Some reflections on Gibson's "Ecological Approach." *Cognition* 9:139–96. [GO, rJKO, ZWP, BJS]

Foulkes, D. (1985) *Dreaming: A cognitive-psychological analysis.* Erlbaum. [AR]

Francis, A. L., Baldwin, K. & Nusbaum, H. C. (2000) Learning to listen: The effects of training on attention to acoustic cues. *Perception and Psychophysics* 62:1668–80. [HCN]

Frederici, A. D., Pfeifer, E. & Hahne, A. (1993) Event-related brain potentials during natural speech processing: Effects of semantic morphological and syntactic violations. *Cognitive Brain Research* 1:183–92. [FI]

Frith, C. D., Perry, R. & Lumer, E. (1999) The neural correlates of conscious experience: An experimental framework. *Trends in Cognitive Sciences* 3:105–14. [GR]

Gainotti, G., D'Erme, P. & Bartolomeo, P. (1991) Early orientation of attention toward the half space ipsilateral to the lesion in patients with unilateral brain damage. *Journal of Neurology, Neurosurgery and Psychiatry* 54:1082–89. [PB]

Gallese, V. (2000) The inner sense of action: Agency and motor representations. *Journal of Consciousness Studies* 7:23–40. [VG]

(2001) The "Shared Manifold" hypothesis: From mirror neurons to empathy. *Journal of Consciousness Studies* 8:33–50. [VG]

Gallese, V., Fadiga, L., Fogassi, L. & Rizzolatti, G. (1996) Action recognition in the premotor cortex. *Brain* 119:593–609. [VG]

Gardner, H. (2001) The philosophy-science continuum. *The Chronicle of Higher Education (Section 2:The Chronicle Review)* 47:B7-B10. [PByR]

Gauthier, G. M. (1976) Alterations of the human vestibulo-ocular reflex in a simulated dive at 62 ATA. *Undersea Biomedical Research* 3(2):103–12. [aJKO]

Gauthier, G. M. & Robinson, D. A. (1975) Adaptation of the human vestibulo-ocular reflex to magnifying lenses. *Brain Research* 92(2):331–35. [aJKO]

Germeys, F., De Graef, P. & Verfaillie, K. (in press) Transaccadic perception of saccade target and flanker objects. *Journal of Experimental Psychology: Human Perception and Performance.* [PDG]

Gerrits, H. J. M. (1967) *Observations with stabilized retinal images and their neural correlates. A theory on the perception of constant brightness.* Doctoral dissertation, Catholic University of Neijmegen, Neijmegen, The Netherlands.

(1978) Differences in peripheral and foveal effects observed in stabilized vision. *Experimental Brain Research* 32(2):225–44. [aJKO]

Gibson, J. J. (1966) *The senses considered as perceptual systems.* Houghton Mifflin. [aJKO, BJS]

(1979/1986) *The ecological approach to visual perception.* Erlbaum. [JRP, BJS]

(1982a) Note on perceiving in a populated environment. In: *Reasons for realism: Selected essays of James J. Gibson,* ed. E. Reed & R. Jones. Erlbaum. [N-GK]

(1982b) Notes on affordances. In: *Reasons for realism: Selected essays of James J. Gibson,* ed. E. Reed & R. Jones. Erlbaum. [aJKO]

Gibson, J. J., Kaplan, G. A., Reynolds, H. N., Jr. & Wheeler, K. (1969) The change from visible to invisible: A study of optical transitions. *Perception and Psychophysics* 5:113–16. [BJS]

Gillam, B. & Chambers, D. (1985) Size and position are incongruous: Measurements on the Müller-Lyer figure. *Perception and Psychophysics* 37:549–56. [JBJS]

Goodale, M. A. & Humphrey, G. K. (1998) The objects of action and perception. *Cognition* 67:179–205. [MAG]

Goodale, M. A. & Milner, A. D. (1992) Separate visual pathways for perception and action. *Trends in Neurosciences* 15(1):20–25. [MAG, aJKO]

Gordon, A. M., Forssberg, H., Johansson, R. S. & Westling, G. (1991) Visual size cues in the programming of manipulative forces during precision grip. *Experimental Brain Research* 83:477–82. [JBJS]

Gorea, A. (1991) Thoughts on the specific nerve energy. In: *Representation of vision. Trends and tacit assumptions in vision research,* ed. A. Gorea. Cambridge University Press. [aJKO]

Gray, C. M., Konig, P., Engel, A. K. & Singer, W. (1989) Oscillatory responses in cat visual-cortex exhibit inter-columnar synchronization which reflects global stimulus properties. *Nature* 338:334–37. [VAFL]

Gray, C. M. & Singer, W. (1989) Stimulus-specific neuronal oscillations in orientation columns of cat visual cortex. *Proceedings of the National Academy of Sciences USA* 86(5):1698–702. [aJKO]

Grealy, M. A., Craig, C. M. & Lee, D. N. (1999) Evidence for on-line visual guidance during saccadic gaze shifts. *Proceedings of the Royal Society of London, Series B: Biological Sciences* 266:1799–804. [BWT]

Green, D. M. & Swets, J. A. (1966) *Signal detection theory and psychophysics.* Wiley. [UA]

Greenhouse, D. S. & Cohn, T. E. (1991) Saccadic suppression and stimulus uncertainty. *Journal of the Optical Society of America [A]* 8(3):587–95. [aJKO]

Greenspan, S. L., Nusbaum, H. C. & Pisoni, D. B. (1988) Perceptual learning of synthetic speech produced by rule. *Journal of Experimental Psychology: Learning, Memory, and Cognition* 14:421–33. [HCN]

Gregory, R. L. (1972) Seeing as thinking: An active theory of perception. *Times Literary Supplement* June 23, 1972:707–708. [VV]

(1973) *Eye and brain. The psychology of seeing.* McGraw Hill. [aJKO]

(1980) Perceptions as hypothesis. *Philosophical Transactions of the Royal Society of London* 290:181–97. [VV]

(1993) Hypothesis and illusion: Explorations in perception and science. In: *New representationalisms: Essays in the philosophy of perception.* Avebury. [EW]

Grimes, J. (1996) On the failure to detect changes in scenes across saccades. In:

Perception, ed. K. Akins. *Vancouver Studies in Cognitive Science, vol. 2.* Oxford University Press. [BJS]
Grüsser, O. J. (1986) Interaction of efferent and afferent signals in visual perception. A history of ideas and experimental paradigms. *Acta Psychologica (Amsterdam)* 63(1–3):3–21. [aJKO]
Guarniero, G. (1974) Experience of tactile vision. *Perception* 3(1):101–104. [aJKO]
(1977) Tactile vision: A personal view. *Visual Impairment and Blindness* 125–30. [aJKO]
Gurwitsch, A. (1964) *The field of consciousness.* Duquesne University Press. [UA]
Gysen, V., De Graef, P. & Verfaillie, K. (2002) Detection of intrasaccadic displacements and depth rotations of moving objects. *Vision Research* 42:379–91. [PDG]
Gysen, V. & Verfaillie, K. (2001) Transaccadic perception of translating objects. Paper presented at the First Annual Meeting of the Vision Sciences Society, Sarasota, Florida, May 2001. [PDG]
Haenny, P. E., Maunsell, J. H. R. & Schiller, P. H. (1988) State dependent activity in monkey visual cortex. *Experimental Brain Research* 69:245–59. [aJKO]
Haines, R. F. (1991) A breakdown in simultaneous information processing. In: *Presbyopia research. From molecular biology to visual adaptation,* ed. G. Obrecht & L. W. Stark. Plenum Press. [FI, aJKO]
Haith, M. M. (1988) Who put the cog in infant cognition? Is rich interpretation too costly? *Infant Behavior and Development* 21:167–79. [MS]
Hallett, P. (1978) Primary and secondary saccades to goals defined by instructions. *Vision Research* 18:1279–96. [BF]
Hardcastle, V. G. (1996) Discovering the moment of consciousness II: An ERP analysis of priming using novel visual stimuli. *Philosophical Psychology* 9:169–98. [VGH]
Harding, G. (1991) Color and the mind-body problem. *Review of Metaphysics* 45:289–307. [EW]
Hari, R., Salmelin, R., Tissari, S. O., Kajola, M. & Virsu, V. (1994) Visual stability during eyeblinks. *Nature (London)* 367:121–22. [VV]
Harnad, S. (1987) Category induction and representation. In: *Categorical perception: The groundwork of cognition,* ed. S. Harnad. Cambridge University Press. [EW]
Harnad, S. (1995) Why and how we are not zombies. *Journal of Consciousness Studies* 1:64–67. http://www.cogsci.soton.ac.uk/~harnad/Papers/Harnad/harnad95.zombies.html [SH]
(2000) Correlation vs. causality: How/Why the mind/body problem is hard. *Journal of Consciousness Studies* 7(4):54–61. http://www.cogsci.soton.ac.uk/~harnad/Papers/Harnad/harnad00.mind.humphrey.html [SH]
(2001) No easy way out. *The Sciences* 41(2):36–42. http://www.cogsci.soton.ac.uk/~harnad/Tp/thesciences.htm [SH]
Harris, C. S. (1965) Perceptual adaptation to inverted, reversed, and displaced vision. *Psychological Review* 72(6):419–44. [aJKO]
(1980) Insight or out of sight?: Two examples of perceptual plasticity in the human adult. In: *Visual coding and adaptability,* ed. C. S. Harris. Erlbaum. [aJKO]
Harth, E. (1993) *The creative loop: How the brain makes a mind.* Addison-Welsey. [PByR]
Harvey, M. (1995) Translation of "Psychic paralysis of gaze, optic ataxia, and spatial disorder of attention" by Rudolph Balint. *Cognitive Neuropsychology* 12:261–82. [aJKO]
Hatwell, Y. (1986) *Toucher l'espace: La main et la perception tactile de l'espace.* Presses Universitaires de Lille. [aJKO]
Hayes, S. P. (1935) *Facial vision or the sense of obstacles.* Perkins. [aJKO]
Hayhoe, M. M., Lachter, J. & Moeller, P. (1992) Spatial memory and integration across saccadic eye movements. In: *Eye movements and visual cognition: Scene perception and reading,* ed. K. Rayner. Springer Verlag. [PDG]
Hebb, D. O. (1947) *The organization of behavior: A neuropsychological approach.* Wiley. [JH]
(1968) Concerning imagery. *Psychological Review* 75:466–77. [JH]
Hecht, H. & Bertamini, M. (2000) Understanding projectile acceleration. *Journal of Experimental Psychology: Human Perception and Performance* 26:730–46. [FL]
Hecht, H., Kaiser, M. K. & Banks, M. S. (1996) Gravitational acceleration as a cue for absolute size and distance? *Perception and Psychophysics* 58:1066–75. [FL]
Heil, (1983) *Perception and cognition.* University of California Press. [aJKO]
Held, R. (1980) The rediscovery of adaptability in the visual system: Effects of extrinsic and intrinsic chromatic dispersion. In: *Visual coding and adaptability,* ed. C. S. Harris. Erlbaum. [aJKO]
Held, R. & Hein, A. (1963) Movement-produced stimulation in the development of visually guided behavior. *Journal of Comparative and Physiological Psychology* 56:872–76. [VV]
Helmholtz, H. von (1909/1925) *Physiological optics, vol. 3,* trans. J. P. C. Southall. Optical Society of America. [aJKO]
Hemeroff, S. R. (1994) Quantum coherence in microtubules: A neural basis for emergent consciousness? *Journal of Consciousness Studies* 1:91–118. [aJKO]
Henderson, J. M. & Siefert, A. (1999) The influence of enantiomorphic transformation on transaccadic object integration. *Journal of Experimental Psychology: Human Perception and Performance* 25:243–55. [PDG]
Hendriks-Jansen, H. (1996) *Catching ourselves in the act.* MIT Press. [MK]
Hobson, J. A. (1988) *The dreaming brain.* Basic Books. [AR]
Hochberg, J. (1968) In the mind's eye. In: *Contemporary theory and research in visual perception,* ed. R. N. Haber. Holt, Rinehart & Winston. [JH, aJKO, ZWP]
(1970) Attention, organization and consciousness. In: *Attention: Contemporary theory and analysis,* ed. D. I. Mostofsky. Appleton-Century-Crofts. [JH, aJKO]
(1974) Higher-order stimuli and interresponse coupling in the perception of the visual world. In: *Perception: Essays in honor of James J. Gibson,* ed. R. B. MacLeod & H. L. Pick. Cornell University Press. [JH]
(1986) Representation of motion and space in video and cinematic displays. In: *Handbook of perception and human performance. Vol. 1: Sensory processes and perception,* ed. K. R. Boff, L. Kaufman & J. P. Thomas. Wiley. [BJS]
(1997) The affordances of perceptual inquiry: Pictures are learned from the world, and what that fact might mean about perception quite generally. In: *Perceptual learning,* ed. R. Goldstone, D. Medin & P. G. Schyns. Academic Press. [JH]
(1998) Gestalt theory and its legacy: Organization in eye and brain, in attention and mental representation. In: *Cognition and perception at century's end,* ed. J. Hochberg. Academic Press. [JH]
(2001) Coupling: Phenomena, problems and opportunities. Paper presented at the Society of Experimental Psychologists Conference, Princeton University, March 30, 2001. [JH]
Hochberg, J. & Brooks, V. (1997) The perception of motion pictures. In: *Handbook of perception and cognition: Cognitive ecology,* ed. M. Friedman & E. Carterette. Academic Press. [JH]
Hoffman, D. D. (1998) *Visual intelligence: How we create what we see.* W. W. Norton. [ZWP]
Holender, D. (1986) Semantic activation without conscious identification in dichotic listening, parafoveal vision, and visual masking: A survey and reappraisal. *Behavioral and Brain Sciences* 9:1–23. [UA]
Hollingworth, A. (2001) The relationship between change detection and visual memory: Evidence from target postcuing. Poster presented at the Annual Meeting of the Psychonomic Society, Orlando, Florida. [JRP]
Hollingworth, A. & Henderson, J. M. (2000) Semantic informativeness mediates the detection of changes in natural scenes. In: *Visual cognition: Change blindness and visual memory,* ed. D. J. Simons. [Special issue of *Visual Cognition*]. Psychology Press. [JRP]
Hollingworth, A., Williams, C. C. & Henderson, J. M. (in press) To see and remember: Visually specific information is retained in memory from previously attended objects in natural scenes. *Psychonomic Bulletin and Review.* [JDR]
Horn, G. & Hill, R. M. (1969)Modifications of the receptive field of cells in the visual cortex occurring spontaneously and associated with bodily tilt. *Nature* 221:185–87. [aJKO]
Howard, I. P. & Templeton, W. B. (1966) *Human spatial orientation.* Wiley. [aJKO]
Howells, T. H. (1944) The experimental development of color-tone synesthesia. *Journal of Experimental Psychology* 34:87–103. [aJKO]
Hubel, D. H. & Wiesel, T. N. (1962) Receptive fields, binocular interaction and functional architecture in the cat's visual cortex. *Journal of Physiology* 160:106–54. [EN]
Hukube, T., Sasaki, T. & Peng, C. (1991) A blind mobility aid modeled after echolocation of bats. *IEEE Transactions on Biomedical Engineering* 38(5):461–65. [aJKO]
Humphrey, G. K. (1951) *Thinking: An introduction to its experimental psychology.* Methuen. [JRP]
Humphrey, G. K., Gumsey, R. & Bryden, P. J. (1994) An examination of colour-contingent pattern aftereffects. *Spatial Vision* 8(1):77–94. [aJKO]
Humphrey, G. K. & Humphrey, D. E. (1985) The use of binaural sensory aids by blind infants and children: Theoretical and applied issues. In: *Applied developmental psychology, vol. 2,* ed. F. Morrison, C. Lord & D. Keating. Academic Press. [aJKO]
Humphrey, N. (1970) What the frog's eye tells the monkey's brain. *Brain, Behavior, Evolution* 3:324–37. [NH]
(1992) *A history of the mind.* Chatto & Windus. [NH]
(2000) How to solve the mind-body problem. *Journal of Consciousness Studies* 7:5–20. [NH]
Intraub, H. & Richardson, M. (1989) Wide-angle memories of close-up scenes.

Journal of Experimental Psychology: Learning, Memory, and Cognition 15(2):179–87. [aJKO]
Iriki, A., Tanaka, M. & Iwamura, Y. (1996) Coding of modified body schema during tool use by macaque postcentral neurones. *NeuroReport* 7(14):2325–30. [aJKO]
Irwin, D. E. (1991) Information integration across saccadic eye movements. *Cognitive Psychology* 23:420–56. [PDG, N-GK, aJKO]
(1992) Perceiving an integrated visual world. In: *Attention and performance XIV: Synergies in experimental psychology, artificial intelligence, and cognitive neuroscience,* ed. D. E. Meyer & S. Kornblum. MIT Press. [aJKO]
Irwin, D. E. & Andrews, R. V. (1996) Integration and accumulation of information across saccadic eye movements. In: *Attention and performance XIV: Information integration in perception and communication,* ed. T. Inui & J. L. McClelland. MIT Press. [aJKO]
Irwin, D. E. & Gordon, R. D. (1998) Eye movements, attention, and transaccadic memory. *Visual Cognition* 5(1–2):127–55. [aJKO]
Isel, F., Hahne, A. & Friederici, A. D. (1999) Syntactic and semantic processes in French spoken sentences: ERP evidence. *Annual Report of the Max Planck Institut of Cognitive Neuroscience,* pp. 19–20. [FI]
James, W. (1890/1950) *The principles of psychology.* Dover/Macmillan. [SJB, aJKO]
Jameson, D. & Hurvich, L. M. (1978) Dichromatic color language: "Reds" and "greens" don't look alike but their colors do. *Sensory Processes* 2:146–55. [aJKO]
Järvilehto, T. (1998a) The theory of the organism-environment system: I. Description of the theory. *Integrative Physiological and Behavioral Science* 33:317–30. [aJKO]
(1998b) The theory of the organism-environment system: II. Significance of nervous activity in the organism-environment system. *Integrative Physiological and Behavioral Science* 33:331–38. [aJKO]
(1999) The theory of the organism-environment system: III. Role of efferent influences on receptors in the formation of knowledge. *Integrative Physiological and Behavioral Science* 34:90–100. [aJKO]
(2000) The theory of the organism-environment system: IV. The problem of mental activity and consciousness. *Integrative Physiological and Behavioral Science* 35:35–57. [aJKO]
Jaskowski, P., van der Lubbe, R., Schlotterbeck, E. & Verleger, R. (2002) Traces left on visual selective attention by not consciously identified stimuli. *Psychological Science* 13:48–54. [UA]
Jeannerod, M. (1975) Déficit visuel persistant chez les aveugles-nés opérés. Données cliniques et expérimentales. *Année Psychologique* 1:169–95. [aJKO]
(1997) *The cognitive neuroscience of action.* Blackwell. [aJKO]
(1999) Visuomotor channels: Their integration in goal-directed prehension. *Human Movement Science* 18:210–18. [JBJS]
Jenkins, W. M., Merzenich, M. M., Ochs, M. T., Allard, T. & Guic-Robles, E. (1990a) Functional reorganization of primary somatosensory cortex in adult owl monkeys after behaviorally controlled tactile stimulation. *Journal of Neurophysiology* 63(1):82–104. [aJKO]
Jenkins, W. M., Merzenich, M. M. & Recanzone, G. (1990b) Neocortical representational dynamics in adult primates: Implications for neuropsychology. *Neuropsychologia* 28(6):573–84. [aJKO]
Jonides, J. & Smith, E. E. (1997) The architecture of working memory. In: *Cognitive neuroscience. Studies in cognition,* ed. M. D. Rugg. MIT Press. [HCN]
Jousmäki, V., Hämäläinen, M. & Hari, R. (1996) Magnetic source imaging during a visually guided task. *NeuroReport* 7:2961–64. [VV]
Jouvet, M. (1999) *The paradox of sleep, the story of dreaming.* MIT Press. [AR]
Kahn, D., Pace-Schott, E. F. & Hobson, J. A. (1997) Consciousness in waking and dreaming: The roles of neuronal oscillation and neuromodulation in determining similarities and differences. *Neuroscience* 78(1):13–38. [aJKO]
Kahneman, D., Treisman, A. & Gibbs, B. J. (1992) The reviewing of object files: Object-specific integration of information. *Cognitive Psychology* 24(2):175–219. [aJKO]
Kandel, E. R. & Schwartz, J. H. (1985) *Principles of neural science, 2nd edition.* Elsevier. [EN]
Kawato, M. (1999) Internal models for motor control and trajectory planning. *NeuroReport* 9:718–27. [VG]
Kelly, D. H. (1981) Disappearance of stabilized chromatic gratings. *Science* 214(4526):1257–58. [aJKO]
(1982) Motion and vision. IV. Isotropic and anisotropic spatial responses. *Journal of the Optical Society of America* 72(4):432–39. [aJKO]
Kelso, J. A. S. & Kay, B. A. (1987) Information and control: A macroscopic analysis of perception-action coupling. In: *Perspectives on perception and action,* ed. H. Heuer & A. F. Sanders. Erlbaum. [aJKO]
Keysers, C., Xiao, D., Foldiak, P. & Perrett, D. I. (2001) The speed of sight. *Journal of Cognitive Neuroscience* 13:90–101. [VG]
Kim, N.-G., Growney, R. & Turvey, M. T. (1996) Optical flow not retinal flow is the basis of wayfinding by foot. *Journal of Experimental Psychology: Human Perception and Performance* 22:1279–88. [N-GK]
Kim, N.-G. & Turvey, M. T. (1999) Eye movements and a rule for perceiving direction of heading. *Ecological Psychology* 11:233–48. [N-GK]
Kingdom, F. & Moulden, B. (1992) A multi-channel approach to brightness coding. *Vision Research* 32(8):1565–82. [aJKO]
Kinsbourne, M. (1970) A model for the mechanism of unilateral neglect of space. *Transactions of the American Neurological Association* 95:143–46. [PB]
(1987) Mechanisms of unilateral neglect. In: *Neurophysiological and neuropsychological aspects of spatial neglect,* ed. M. Jeannerod. North Holland. [aJKO]
(1993) Orientational bias model of unilateral neglect: Evidence from attentional gradients within hemispace. In: *Unilateral neglect: Clinical and experimental studies,* ed. I. H. Robertson & J. C. Marshall. Erlbaum. [PB]
(1995) Awareness of one's own body: An attentional theory of its nature, development and brain basis. In: *The body and the self,* ed. J. L. Bermudez, A. Marcel & N. Eilan. MIT Press. [aJKO]
Kleinschmidt, A., Buchel, C., Zeki, S. & Frackowiak, R. S. J. (1998) Human brain activity during spontaneously reversing perception of ambiguous figures. *Proceedings of the Royal Society of London B* 265:2427–33. [GR]
Klotz, W. & Neumann, O. (1999) Motor activation without conscious discrimination in metacontrast masking. *Journal of Experimental Psychology: Human Perception and Performance* 25:976–92. [UA]
Klotz, W. & Wolff, P. (1995) The effect of a masked stimulus on the response to the masking stimulus. *Psychological Research/Psychologische Forschung* 58:92–101. [UA]
Koenderink, J. J. (1984a) The concept of local sign. In: *Limits in perception,* ed. A. J. van Doorn, W. A. van de Grind & J. J. Koenderink. VNU Science Press. [aJKO]
(1984b) The internal representation of solid shape and visual exploration. In: *Sensory experience, adaptation, and perception. Festschrift for Ivo Kohler,* ed. L. Spillmann & B. R. Wooten. Erlbaum. [aJKO]
Kohler, I. (1951) Über Aufbau und Wandlungen der Wahmehmungswelt. *Österreichische Akademie der Wissenschaften. Sitzungsberichte, philosophisch-historische Klasse* 227:1–118. [aJKO]
(1967) Facial vision rehabilitated. In: *Les systèmes sonars animaux, vol. 1,* ed. R.-G. Busnel. Laboratoire de Physiologie Acoustique. [aJKO]
Kosslyn, S. M. (1980) *Image and mind.* Harvard University Press. [PByR]
(1994) *Image and brain. The resolution of the imagery debate.* MIT Press. [aJKO]
Kosslyn, S. M., Thompson, W. L., Kim, I. J. & Alpert, N. M. (1995) Topographical representations of mental images in primary visual cortex. *Nature* 378(30):496–98. [RM]
Kottenhoff, H. (1961) *Was ist richtiges Sehen mit Unkehrbrillen und in welchem Sinne stellt sich das Sehen um?* A. Hain. [aJKO]
Kowler, E. & Steinman, R. M. (1977) The role of small saccades in counting. *Vision Research* 17(1):141–46. [aJKO]
Krauskopf, J. (1963) Effect of retinal image stabilization of the appearance of heterochromatic targets. *Journal of the Optical Society of America* 53:741–44. [aJKO]
Kurthen, M., Grunwald, T. & Elger, C. E. (1998) Will there be a neuroscientific theory of consciousness? *Trends in Cognitive Sciences* 2:229–34. [MK]
Kustov, A. A. & Robinson, D. L. (1996) Shared neural control of attentional shifts and eye movements. *Nature* 384:74–77. [aJKO]
Lacquaniti, F. (1996) Neural control of limb mechanics for visuomanual coordination. In: *Hand and brain: The neurophysiology and psychology of hand function,* ed. A. M. Wing, P. Haggard & J. R. Flanagan. Academic Press. [FL]
Lacquaniti, F., Borghese, N. A. & Carrozzo, M. (1992) Internal models of limb geometry in the control of hand compliance. *Journal of Neuroscience* 12:1750–62. [FL]
Lacquaniti, F., Carrozzo, M. & Borghese, N. A. (1993a) The role of vision in tuning anticipatory motor responses of the limbs. In: *Multisensory control of movement,* ed. A. Berthoz. Oxford University Press. [FL]
(1993b) Time-varying mechanical behavior of multijointed arm in man. *Journal of Neuroscience* 69:1443–64. [FL]
Lacquaniti, F. & Maioli, C. (1989a) The role of preparation in tuning anticipatory and reflex responses during catching. *Journal of Neuroscience* 9:134–48. [FL]
(1989b) Adaptation to suppression of visual information during catching. *Journal of Neuroscience* 9:149–59. [FL]
Làdavas, E., Carletti, M. & Gori, G. (1994) Automatic and voluntary orienting of attention in patients with visual neglect: Horizontal and vertical dimensions. *Neuropsychologia* 32:1195–208. [PB]
Lakoff, G. & Johnson, M. (1999) *Philosophy in the flesh.* Basic Books. [MK]
Laming, D. (1986) *Sensory analysis.* Academic Press. [aJKO]
(1988) A re-examination of sensory analysis. *Behavioral and Brain Sciences* 11:316–39. [aJKO]

Lamme, V. A. F. (2000) Neural mechanisms of visual awareness; a linking proposition. *Brain and Mind* 1:385–406. [VAFL]

Lamme, V. A. F., Super, H., Landman, R., Roelfsema, P. R. & Spekreijse, H. (2000) The role of primary visual cortex (V1) in visual awareness. *Vision Research* 40:1507–21. [VAFL]

Land, M., Mennie, N. & Rusted, J. (1999) The roles of vision and eye movements in the control of activities of daily living. *Perception* 28:1311–28. [BWT]

Lang, C. E. & Bastian, A. J. (1999) Cerebellar subjects show impaired adaptation of anticipatory EMG during catching. *Journal of Neurophysiology* 82:2108–19. [FL]

Lee, D. N. & Lishman, J. R. (1977) Visual control of locomotion. *Scandinavian Journal of Psychology* 18:224–30. [N-GK]

Lenay, C. (1997) Le mouvement des boucles sensori-motrices aux représentations cognitives et langagières. Paper presented at the Sixième Ecole d'Eté de l'Association pour la Recherche Cognitive. [VG, aJKO]

Lenay, C., Canu, S. & Villon, P. (1997) Technology and perception: The contribution of sensory substitution systems. Paper presented at the Second International Conference on Cognitive Technology, Aizu, Japan. [aJKO]

Lenay, C., Gapenne, O., Hanneton, S. & Marque, C. (1999) La suppléance sensorielle: Limites et perspectives. In: *Toucher pour connaître. Psychologie cognitive de la perception tactile manuelle,* ed. Y. Hatwell, A. Streri & E. Gentaz. Presses Universitaire de France. [aJKO]

Leopold, D. A. & Logothetis, N. K. (1996) Activity changes in early visual cortex reflect monkeys' percepts during binocular rivalry. *Nature* 379(6565):549–53. [aJKO]

(1999) Multistable phenomena: Changing views in perception. *Trends in Cognitive Studies* 3(7):254–65. [aJKO]

Leuthold, H. & Kopp, B. (1998) Mechanisms of priming by masked stimuli: Inferences from event-related brain potentials. *Psychological Science* 9:263–69. [UA]

Levi, D. M., Klein, S. A. & Aitsebaomo, A. P. (1985) Vernier acuity, crowding and cortical magnification. *Vision Research* 25(7):963–77. [aJKO]

Levin, D. T., Momen, N., Drivdahl, S. B. & Simons, D. J. (2000) Change blindness blindness: The metacognitive error of overestimating change-detection ability. *Visual Cognition* 7:397–412. [BJS]

Levin, D. T., Simons, D. J., Angelone, B. L. & Chabris, C. F. (in press) Memory for centrally attended changing objects in an incidental real-world change detection paradigm. *British Journal of Psychology.* [BJS]

Lévy-Schoen, A. (1969) Détermination et latence de la résponse oculomotrice à deux stimulus. *L'Annee Psychologique* 69:373–92. [BMV]

Lewicki, P., Czyzewska, M. & Hoffman, H. (1987) Unconscious acquisition of complex procedural knowledge. *Journal of Experimental Psychology: Learning, Memory, and Cognition* 13:523–30. [VGH]

Lewicki, P., Hill, T. & Czyzewska, M. (1992) Nonconscious acquisition of information. *American Psychologist* 47:796–801. [VGH]

Li, W. & Matin, L. (1990) Saccadic suppression of displacement: Influence of postsaccadic exposure duration and of saccadic stimulus elimination. *Vision Research* 30(6):945–55. [aJKO]

(1997) Saccadic suppression of displacement: Separate influences of saccadic size and of target retinal eccentricity. *Vision Research* 37(13):1779–97. [aJKO]

Liberman, A. M. (1957) Some results of research on speech perception. *Journal of the Acoustical Society of America* 29:117–23. [JH]

Liberman, A. M., Cooper, F. S., Shankweiler, D. P. & Studdert-Kennedy, M. (1967) Perception of the speech code. *Psychological Review* 74:431–61. [HCN]

Liberman, A. M. & Mattingly, I. G. (1985) The motor theory of speech perception revised. *Cognition* 21:1–36. [HCN]

Lichtenstein, E. H. & Brewer, W. F. (1980) Memory for goal-directed events. *Cognitive Psychology* 12:412–45. [JRP]

Lillo, J., Davies, J. R., Collado, J., Ponte, C. & Vitini, J. (1998) Colour memory dichromats is more accurate than the standard model predicts. *Perception* 27:175. [aJKO]

Linden, D. E. J., Kallenbach, U., Heinecke, A., Singer, W. & Goebel, R. (1999) The myth of upright vision. A psychophysical and functional imaging study of adaptation to inverting spectacles. *Perception* 28:469–81. [aJKO]

Livingstone, M. & Hubel, D. (1988) Segregation of form, color, movement and depth: Anatomy, physiology and perception. *Nature* 240:740–49. [aJKO]

Llinas, R. & Ribary, U. (1993) Coherent 40-Hz oscillation characterizes dream state in humans. *Proceedings of the National Academy of Sciences USA* 90(5):2078–81. [aJKO]

Loftus, G. R. & Mackworth, N. H. (1978) Cognitive determinants of fixation location during picture viewing. *Journal of Experimental Psychology: Cognition, Perception, and Performance* 4(4):565–72. [JDR]

Logothetis, N. K. (1998) Single units and conscious vision. *Philosophical Transactions of the Royal Society of London B: Biological Sciences* 353(1377):1801–18. [aJKO]

Logothetis, N. K., Leopold, D. A. & Sheinberg, D. L. (1996) What is rivalling during binocular rivalry? [see comments]. *Nature* 380(6575):621–24. [aJKO]

Lotze, H. (1885) *Metaphysics.* Clarendon Press. [EW]

Lowe, E. J. (1981) Indirect perception and sense-data. *Philosophical Quarterly* 31:330–42. [EW]

(1996) *Subjects of experience.* Cambridge University Press. [EW]

Lumer, E. (2000) Binocular rivalry and human visual awareness. In: *Neural correlates of consciousness: Conceptual and empirical questions,* ed. T. Metzinger. MIT Press. [GR]

Mack, A. & Bachant, J. (1969) Perceived movement of the afterimage during eye movements. *Perception and Psychophysics* 6:379–84. [aJKO]

Mack, A. & Rock, I. (1998) *Inattentional blindness.* MIT Press. [aJKO]

Mack, A., Tang, B. Tuma, R., Kahn, S. & Rock, I. (1992) Perceptual organization and attention. *Cognitive Psychology* 24(4):475–501. [aJKO]

MacKay, D. M. (1962) Theoretical models of space perception. In: *Aspects of the theory of artificial intelligence,* ed. C. A. Muses. Plenum Press. [DCD, aJKO]

(1967) Ways of looking at perception. In: *Models for the perception of speech and visual form,* ed. W. Wathen-Dunn. MIT Press. [DCD, aJKO]

(1973) Visual stability and voluntary eye movements. In: *Handbook of sensory physiology, vol. VII/3A,* ed. R. Jung. Springer. [DCD, aJKO]

Malcolm, N. (1984) Consciousness and causality. In: *Consciousness and causality,* ed. D. M. Armstrong & N. Malcolm. Blackwell. [aJKO]

Manzotti, R. & Tagliasco, V. (2001) *Coscienza e realtà.* Il Mulino. [RM]

Marbach, E. (1994) Troubles with heterophenomenology. In: *Philosophy and the cognitive sciences,* ed. R. Casati, B. Smith & G. White. Hölder-Pickler-Tempsky. [aJKO]

Marcos, S., Navarro, R. & Artal, P. (1996) Coherent imaging of the cone mosaic in the living human eye. *Journal of the Optical Society of America* 13(5):897–905. [aJKO]

Mareschal, D., Plunkett, K. & Harris, P. (1999) A computational and neuropsychological account of object-oriented behaviours in infancy. *Developmental Science* 2:306–17. [MS]

Marks, L. E. (1978) *The unity of the senses. Interrelations among the modalities.* Academic Press. [aJKO]

Marr, D. (1982) *Vision: A computational investigation into the human representation and processing of visual information.* W. H. Freeman. [rJKO, ZWP]

Marshall, J. C. & Halligan, P. W. (1989) Does the midsagittal plane play any privileged role in "left" neglect? *Cognitive Neuropsychology* 6(4):403–22. [PB]

Matilal, B. K. (1986) *Perception: An essay on classical Indian theories of knowledge.* Clarendon Press. [EW]

Matin, E. (1974) Saccadic suppression: A review and an analysis. *Psychological Bulletin* 81(12):899–917. [aJKO]

Matin, L. (1972) Eye movements and perceived visual direction. In: *Handbook of sensory physiology. Vol. VII/4: Visual psychophysics,* ed. D. Jameson & L. M. Hurvich. Springer-Verlag. [aJKO]

(1986) Visual localization and eye movements. In: *Handbook of perception and human performance, vol. 1,* ed. K. R. Boff, L. Kaufman & J. P. Thomas. Wiley. [aJKO]

Maturana, H. R. & Varela, F. J. (1989/1992) *The tree of knowledge: The biological roots of human understanding.* Revised Edition. Shambala. [aJKO]

Maund, J. B. (1975) The representative theory of perception. *Canadian Journal of Philosophy* 5(1):41–55. [EW]

(1993) Representation, pictures and resemblance. In: *New representationalisms: Essays in the philosophy of perception,* ed. E. Wright. Avebury. [EW]

(1995) *Colours: Their nature and representation.* Cambridge University Press. [EW]

McCollough, C. (1965a) Color adaptation of edge-detectors in the human visual system. *Science* 149:1115–16. [aJKO]

(1965b) The conditioning of color perception. *American Journal of Psychology* 78:362–68. [aJKO]

McConkie, G. W. & Currie, C. B. (1996) Visual stability across saccades while viewing complex pictures. *Journal of Experimental Psychology: Human Perception and Performance* 22(3):563–81. [aJKO]

McConkie, G. W. & Zola, D. (1979) Is visual information integrated across successive fixations in reading? *Perception and Psychophysics* 25(3):221–24. [rJKO, BJS]

McGurk, H. & MacDonald, J. (1976) Hearing lips and seeing voices. *Nature* 264(5588):746–48. [aJKO]

McIntyre, J., Zago, M., Berthoz, A. & Lacquaniti, F. (2001) Does the brain model Newton's laws. *Nature Neuroscience* 4:693–94. [FL]

Meltzoff, A. N. & Moore, M. K. (1998) Object representation, identity, and the paradox of early permanence: Steps toward a new framework. *Infant Behavior and Development* 21:201–35. [MS]

Merleau-Ponty, M. (1968) *Résumés de cours au Collège de France.* Gallimard. [aJKO]

Merzenich, M. M., Nelson, R. J., Kaas, J. H., Stryker, M. P., Jenkins, W. M., Zook, J. M., Cynader, M. S. & Schoppmann, A. (1987) Variability in hand surface representations in areas 3b and 1 in adult owl and squirrel monkeys. *Journal of Comparative Neurology* 258(2):281–96. [aJKO]

Merzenich, M. M., Nelson, R. J., Stryker, M. P., Cynader, M. S., Schoppmann, A. & Zook, J. M. (1984) Somatosensory cortical map changes following digit amputation in adult monkeys. *Journal of Comparative Neurology* 224(4):591–605. [aJKO]

Miller, G. A. (1984) Informavores. In: *The study of information: Interdisciplinary messages,* ed. F. Machlup & U. Mansfield. Wiley. [ZWP]

Milner, A. D. & Goodale, M. A. (1995) *The visual brain in action.* Oxford University Press. [UA, SJB, AC, MAG, aJKO, ZWP]

Milner, A. D., Perrett, D. I., Johnston, R. S., Benson, P. J., Jordan, T. R., Heeley, D. W., Bettucci, D., Mortara, F., Mutani, R., Terazzi, E. & Davidson, D. L. W. (1991) Perception and action in "visual form agnosia." *Brain* 114:405–28. [aJKO]

Milner, P. M. (1974) A model for visual shape recognition. *Psychological Review* 81:521–35. [aJKO]

Minsky, M. (1988) *The society of mind.* Simon & Schuster. [arJKO]

Mokler, A. & Fischer, B. (1999) The recognition and correction of involuntary saccades in an antisaccade task. *Experimental Brain Research* 125:511–16. [BF]

Moran, J. & Desimone, R. (1985) Selective attention gates visual processing in extrastriate cortex. *Science* 229:782–84. [aJKO]

Morell, F. (1972) Visual system's view of acoustic space. *Nature* 238:44–46. [aJKO]

Morgan, M. J. (1977) *Molyneux's question. Vision, touch and the philosophy of perception.* Cambridge University Press. [aJKO]

Müller, G. E. (1896) Zur Psychophysik der Gesichtsempfindungen. (Concerning the psychophysics of visual sensations). *Zeitschrift für Psychologie* 10:1–82. [ZWP]

Müller, H. J. & Rabbitt, P. M. (1989) Reflexive and voluntary orienting of visual attention: Time course of activation and resistance to interruption. *Journal of Experimental Psychology: Human Perception and Performance* 15(2):315–30. [PB]

Müller, J. (1838) *Handbuch der Physiologie des Menschen.* Hölscher. [aJKO]

Munakata, Y., McClelland, J. L., Johnson, M. H. & Siegler, R. S. (1997) Rethinking infant knowledge: Toward an adaptive process account of successes and failures in object permanence tasks. *Psychological Review* 104:686–713. [MS]

Nakajima, N. & Shimojo, S. (1981) Adaptation to the reversal of binocular depth cues: Effects of wearing left-right reversing spectacles on stereoscopic depth-perception. *Perception* 10:391–402. [EW]

Nazir, T. A. & O'Regan, J. K. (1990) Some results on translation invariance in the human visual system. *Spatial Vision* 5(2):81–100. [aJKO]

Neisser, U. (1967) *Cognitive psychology.* Appleton-Century-Crofts. [JH, GR]

(1976) *Cognition and reality: Principles and implications of cognitive psychology.* W. H. Freeman. [aJKO, JRP]

Neisser, U. & Becklen, R. (1975) Selective looking: Attending to visually-specified events. *Cognitive Psychology* 7:480–94. [JH, aJKO]

Neumann, O. (1989) Kognitive Vermittlung und direkte Parameterspezifikation. Zum Problem mentaler Repräsentation in der Wahrnehmung. [Cognitive mediation and direct parameter specification. On the problem of mental representation in perception.] *Sprache und Kognition* 8:32–49. [UA]

(1990) Direct parameter specification and the concept of perception. *Psychological Research/Psychologische Forschung* 52:207–15. [UA]

Neumann, O., Ansorge, U. & Klotz, W. (1998) Funktionsdifferenzierung im visuellen Kortex: Grundlage für motorische Aktivierung durch nicht bewußt wahrgenommene Reize? [Functional differentiation in the visual cortex: Basis for motor activation by not consciously perceived stimuli?] *Psychologische Rundschau* 49:185–96. [UA]

Neumann, O. & Klotz, W. (1994) Motor responses to nonreportable, masked stimuli: Where is the limit of direct parameter specification? In: *Attention and performance XV: Conscious and nonconscious information processing,* ed. C. Umiltà & M. Moscovitch. MIT Press. [UA]

Nijhawan, R. (1994) Motion extrapolation in catching. *Nature* 370:256–57. [JBJS]

Noë, A. (1997) Perception and content. *Behavioral and Brain Sciences* 21(1):154–55. [aJKO]

(2001) Experience and the active mind. *Synthese* 29:41–60. [aJKO]

(2002) On what we see. *Pacific Philosophical Quarterly* 83(1):57–80. [aJKO]

Noë, A. & O'Regan, J. K. (2000) Perception, attention, and the grand illusion. *PSYCHE* 6(15). http://psyche.cs.monash.edu.au/v6/psche-6-15-noe.html [aJKO]

Noë, A. Pessoa, L. & Thompson, E. (2000) Beyond the grand illusion: What change blindness really teaches us about vision. *Visual Cognition* 7:93–106. [aJKO]

Noë, A. & Thompson, E. (in press) Neural correlates of consciousness and the matching-content doctrine. *Journal of Consciousness Studies.* [rJKO]

Nolfi, S. & Parisi, D. (1999) Exploiting the power of sensory-motor coordination. In: *Advances in artificial life: Proceedings of the Fifth European Conference on Artificial Life,* ed. D. Floreano, J.-D. Nicoud & F. Mondada. Springer-Verlag. [MS]

Norman, D. A. (1969) *Memory and attention.* Wiley. [JRP]

Norman, R. A., Maynard, E. M., Rousche, P. J. & Warren, D. J. (1999) A neural interface for a cortical vision prosthesis. *Vision Research* 39(15):2577–87. [ZWP]

Noton, D. & Stark, L. (1971) Eye movements and visual perception. *Scientific American* 224(6):35–43. [aJKO]

Nusbaum, H. C., Alperin, N., Towle, V. L., Francis, A. L., Barshes, N., Yarger, R., Small, S. & Solodkin, A. (1999) Cortical localization of linguistic expectations. Paper presented at the Psychonomics Society, Los Angeles. [HCN]

Nusbaum, H. C. & Henly, A. S. (1992) Listening to speech through an adaptive window of analysis. In: *The processing of speech: From the auditory periphery to word recognition,* ed. B. Schouten. Mouton-De Gruyter. [HCN]

Nusbaum, H. C. & Magnuson, J. S. (1997) Talker normalization: Phonetic constancy as a cognitive process. In: *Talker variability in speech processing,* ed. K. A. Johnson & J. W. Mullennix. Academic Press. [HCN]

Nusbaum, H. C. & Morin, T. M. (1992) Paying attention to differences among talkers. In: *Speech perception, production and linguistic structure,* ed. Y. Tohkura, E. Vatikiotis-Bateson & Y. Sagisaka. OHM Publishing. [HCN]

Nusbaum, H. C. & Schwab, E. C. (1986) The role of attention and active processing in speech perception. In: *Pattern recognition by humans and machines: Vol. 1, Speech perception,* ed. E. C. Schwab & H. C. Nusbaum. Academic Press. [HCN]

O'Brien, G. & Opie, J. (1999) A connectionist theory of phenomenal experience. *Behavioral and Brain Sciences* 21:127–96. [RM]

O'Keefe, J., Burgess, N., Donnett, J. G., Jeffery, K. J. & Maguire, E. A. (1998) Place cells, navigational accuracy, and the human hippocampus. *Philosophical Transactions of the Royal Society of London (B): Biological Sciences* 353(1373):1333–40. [aJKO]

O'Regan, J. K. (1984) Retinal versus extraretinal influences in flash localization during saccadic eye movements in the presence of a visible background. *Perception and Psychophysics* 36(1):1–14. [aJKO]

(1992) Solving the "real" mysteries of visual perception: The world as an outside memory. *Canadian Journal of Psychology* 46(3):461–88. [PB, JH, aJKO, BJS]

O'Regan, J. K., Deubel, H., Clark, J. J. & Rensink, R. A. (2000) Picture changes during blinks: Looking without seeing and seeing without looking. *Visual Cognition* 7:191–212. [aJKO]

O'Regan, J. K. & Lévy-Schoen, A. (1983) Integrating visual information from successive fixations: Does trans-saccadic fusion exist? *Vision Research* 23(8):765–68. [JS]

O'Regan, J. K., Rensink, J. A. & Clark, J. J. (1996) "Mud splashes" render picture changes invisible. *Investigative Ophthalmology and Visual Science* 37:S213. [aJKO]

(1999) Change-blindness as a result of "mudsplashes." *Nature* 398:34. [aJKO]

Paillard, J. (1971) Les déterminants moteurs de l'organisation spatiale. *Cahiers de Psychologie* 14:261–316. [aJKO]

(1991) Motor and representational framing of space. In: *Brain and space,* ed. J. Paillard. Oxford University Press. [aJKO]

Palmer, S. (1999a) Color, consciousness, and the isomorphism constraint. *Behavioral and Brain Sciences* 22:923–89. [KO]

(1999b) *Vision science: Photons to phenomenology.* MIT Press. [GO]

Pani, J. R. (1996) Mental imagery as the adaptationist views it. *Consciousness and Cognition* 5:288–326. [JRP]

(2000) Cognitive description and change blindness. In: *Visual cognition: Change blindness and visual memory,* ed. D. J. Simons. [Special issue of *Visual Cognition*]. Psychology Press. [JRP]

Pannasch, S., Dornhoefer, S. M., Unema, P. J. A. & Velichkovsky, B. M. (2001) The omnipresent prolongation of visual fixations. *Vision Research* 41(25–26):3345–51. [BMV]

Paradiso, M. A. & Nakayama, K. (1991) Brightness perception and filling-in. *Vision Research* 31(7–8):1221–36. [aJKO]

Parker, R. E. (1978) Picture processing during recognition. *Journal of Experimental Psychology: Human Perception and Performance* 4(2):284–93. [JDR]

Parks, T. E. (1965) Post-retinal visual storage. *American Journal of Psychology* 78:145–47. [ZWP]

Pascual-Leone, A., Cammarota, A., Wassermann, E. M., Brasil-Neto, J. P., Cohen, L. G. & Hallett, M. (1993) Modulation of motor cortical outputs to the reading hand of Braille readers. *Annals of Neurology* 34(1):33–37. [aJKO]

Pascual-Leone, A. & Walsh, V. (2001) Fast backprojections from the motion to the primary visual area necessary for visual awareness. *Science* 292(5516):510–12. [GR]

Penfield, W. & Jasper, H. (1954) *Epilepsy and the functional anatomy of the human brain.* Little, Brown. [aJKO]

Penrose, R. (1994) *Shadows of the mind.* Oxford University Press. [aJKO]

Peper, L., Bootsma, R. J., Mestre, D. R. & Bakker, F. C. (1994) Catching balls: How to get the hand to the right place at the right time. *Journal of Experimental Psychology: Human Perception and Performance* 20:591–612. [FL]

Pessoa, L., Thompson, E. & Noë, A. (1998) Finding out about filling in: A guide to perceptual completion for visual science and the philosophy of perception. *Behavioral and Brain Sciences* 21(6):723–802. [aJKO]

Peterhans, E. & von der Heydt, R. (1989) Mechanisms of contour perception in monkey visual cortex. II. Contours bridging gaps. *Journal of Neuroscience* 9(5):1749–63. [aJKO]

Peterson, M. R., Kramer, A. F., Wang, R. F., Irwin, D. E. & McCarley, J. S. (2001) Visual search has memory. *Psychological Science* 12(4):287–92. [JDR]

Petitot, J., Varela, F. J., Pachoud, B. & Roy, J.-M. (1999) *Naturalizing phenomenology.* Stanford University Press. [aJKO]

Pfeifer, R. & Scheier, C. (1999) *Understanding intelligence.* MIT Press. [MK]

Phillips, W. A. (1974) On the distinction between sensory storage and short-term visual memory. *Perception and Psychophysics* 16:283–90. [rJKO, BJS]

Piaget, J. (1970) *Genetic epistemology.* Columbia University Press. [EW]

Plato (1929) *Timaeus. Critias. Cleitophon. Menexenus. Episteles.* With an English translation by R. G. Bury. (Loeb Clasical Library, *Plato, vol. IX*). Harvard University Press. [JB]

Platt, J. R. (1960) How we see straight lines. *Scientific American* 202(6):121–29. [aJKO]

Poincaré, H. (1905) *La valeur de la science.* Flammarion. [aJKO]

Pollatsek, A., Rayner, K. & Collins, W. E. (1984) Integrating pictorial information across eye movements. *Journal of Experimental Psychology: General* 113:426–42. [PDG]

Pöppel, E., Held, R. & Frost, D. (1973) Residual visual function after brain wounds involving the central visual pathways in man. *Nature* 243(405):295–96. [aJKO]

Posner, M. I. (1994) Attention: The mechanisms of consciousness. *Proceedings of the National Academy of Sciences USA* 91(16):7398–403. [PB]

Posner, M. I., Snyder, C. R. & Davidson, B. J. (1980) Attention and the detection of signals. *Journal of Experimental Psychology* 109:160–74. [HCN]

Posner, M. I., Walker, J. A., Friedrich, F. J. & Rafal, R. D. (1984) Effects of parietal injury on covert orienting of attention. *Journal of Neuroscience* 54:1863–74. [PB]

Potter, M. C. (11976) Short-term conceptual memory for pictures. *Journal of Experimental Psychology: Human Learning* 2(5):509–22. [aJKO]

Pouget, A. & Sejnowski, T. J. (1997) A new view of hemineglect based on the response properties of parietal neurones. *Philosophical Transactions of the Royal Society of London (B): Biological Sciences* 352(1360):1449–59. [aJKO]

Price, H. H. (1961) *Perception.* Methuen. [EW]

Prinz, J. (2000) The ins and outs of consciousness. *Brain and Mind* 1(2):245–56. [AC]

Pylyshyn, Z. W. (1988) The imagery debate: Analogue media versus tacit knowledge. In: *Readings in cognitive science: A perspective from psychology and artificial intelligence,* ed. E. E. S. Allan & M. Collins. Morgan Kaufmann. [aJKO]

(2001) Visual indexes, preconceptual objects, and situated vision. *Cognition* 80(1/2):127–58. [ZWP]

(forthcoming) Mental imagery: In search of a theory. *Behavioral and Brain Sciences.* [ZWP]

Radeau, M. (1997) Du ventriloque à l'embryon: Une résponse à Molyneux. In: *Perception et intermodalité. Approches actuelles de la question de Molyneux,* ed. J. Proust. Presses Universitaires de France. [aJKO]

Radeau, M. & Bertelson, P. (1974) The after-effects of ventriloquism. *Quarterly Journal of Experimental Psychology* 26(1):63–71. [aJKO]

Rainville, R. E. (1994) The role of dreams in the rehabilitation of the adventitiously blind. *Dreaming* 4(3):155–64. [AR]

Ramachandran, V. S. (1992) Filling in gaps in perception: I. *Current Directions in Psychological Science* 1(6):199–205. [aJKO]

(1995) Filling in gaps in logic: Reply to Durgin et al. *Perception* 24(7):841–45. [aJKO]

Ramachandran, V. S. & Blakeslee, S. (1998) *Phantoms in the brain.* William Morrow. [aJKO]

Ramachandran, V. S., Cobb, S. & Levi, L. (1994a) Monocular double vision in strabismus [letter]. *NeuroReport* 5(12):1418. [aJKO]

(1994b) The neural locus of binocular rivalry and monocular diplopia in intermittent exotropes. *NeuroReport* 5(9):1141–44. [aJKO]

Ramachandran, V. S. & Gregory, R. L. (1991) Perceptual filling in of artificially induced scotomas in human vision. *Nature* 350(6320):699–702. [aJKO]

Rees, G. (2001) Neuroimaging of visual awareness in patients and normal subjects. *Current Opinions in Neurobiology* 11(2):150–56. [GR]

Rees, G., Wojciulik, E., Clarke, K., Husain, M., Frith, C. & Driver, J. (2000) Unconscious activation of visual cortex in the damaged right hemisphere of a parietal patient with extinction. *Brain* 123(Pt 8):1624–33. [GR]

Regan, D. M. & Beverly, K. I. (1982) How do we avoid confounding the direction we are looking and the direction we are moving? *Science* 215:194–96. [N-GK]

Reid, T. (1785/1969) *Essays on the intellectual powers of man.* MIT Press. [NH]

Reingold, E. M. & Merikle, P. M. (1988) Using direct and indirect measures to study perception without awareness. *Perception and Psychophysics* 44:563–75. [UA]

Reingold, E. M. & Stampe, D. (2000) Saccadic inhibition and gaze contingent research paradigm. In: *Reading as perceptual process,* ed. A. Kennedy, R. Raddach, D. Heller & J. Pynte. Elsevier. [BMV]

Rensink, R. A. (2000) Seeing, sensing, and scrutinizing. *Vision Research* 40(10–12):1469–87. [BWT]

Rensink, R. A., O'Regan, J. K. & Clark, J. J. (1997) To see or not to see: The need for attention to perceive changes in scenes. *Psychological Science* 8(5):368–73. [aJKO]

(2000) On the failure to detect changes in scenes across brief interruptions. *Visual Cognition* 7(1/2/3):127–46. [aJKO]

Rep, M., Just, M. A., van Dijl, J. M., Carpenter, P. A., Suda, K., Keller, T. A., Schatz, G. & Eddy, W. (1996) Brain activation modulated by sentence comprehension. *Science* 274:114–16. [HCN]

Revonsuo, A. (1995) Consciousness, dreams, and virtual realities. *Philosophical Psychology* 8:35–58. [AR]

(1998) Visual perception and subjective visual awareness. *Behavioral and Brain Sciences* 21(6):769–70. [AR]

(2000) Prospects for a scientific research program on consciousness. In: *Neural correlates of consciousness,* ed. T. Metzinger. MIT Press. [AR]

(2001) Can functional brain imaging discover consciousness in the brain? *Journal of Consciousness Studies* 8(3):3–23. [AR]

Rice, C. E. (1966) *The human sonar system, vol. II.* Paper presented at the Animal Sonar Systems Conference: Biology and bionics. NATO Advanced Study Institute, Frascati, Italy. [aJKO]

Richards, W. (1969) Saccadic suppression. *Journal of the Optical Society of America* 59:617–23. [aJKO]

Richards, W., ed. (1988) *Natural computation.* MIT Press/A Bradford Book. [ZWP]

Ridder, W. H., 3rd & Tomlinson, A. (1997) A comparison of saccadic and blink suppression in normal observers. *Vision Research* 37(22):3171–79. [aJKO]

Rivera, S. M., Wakeley, A. & Langer, J. (1999) The drawbridge phenomenon: Representational reasoning or perceptual preference? *Developmental Psychology* 35:427–35. [MS]

Rizzolatti, G. & Arbib, M. A. (1998) Language within our grasp. *Trends in Neurosciences* 21:188–94. [HCN]

Rizzolatti, G., Fadiga, L., Gallese, V. & Fogassi, L. (1996) Premotor cortex and the recognition of motor actions. *Cognitive Brain Research* 3:131–41. [VG]

Rizzolatti, G., Matelli, M. & Pavesi, G. (1983) Deficit in attention and movement following the removal of postarctuate (area 6) and prearctuate (area 8) cortex in monkey. *Brain* 106:655–73. [aJKO]

Rizzolatti, G., Riggio, L. & Sheliga, B. M. (1994) Space and selective attention. In: *Attention and performance XV,* C. Umiltà & M. Moscovitch. MIT Press. [aJKO]

Robertson, I. H. & Hawkins, K. (1999) Limb activation and unilateral neglect. *Neurocase* 3:153–60. [PB]

Rodriguez, E., George, N., Lachaux, J.-P., Martinerie, J., Renault, B. & Varela, F. J. (1999) Perception's shadow: Long-distance synchronization of human brain activity. *Nature* 397:430–33. [aJKO]

Roediger, H. L. (1990) Implicit memory: Retention without remembering. *American Psychologist* 45:1043–56. [JDR]

Rogers, B. & Graham, M. (1979) Motion parallax as an independent cue for depth perception. *Perception* 8(2):125–34. [aJKO]

Rogers, S. & Rogers, B. J. (1992) Visual and nonvisual information disambiguate surfaces specified by motion parallax. *Perception and Psychophysics* 52(4):446–52. [aJKO]

Rolls, E. T. (1992) Neurophysiological mechanisms underlying face processing within and beyond the temporal cortical visual areas. *Philosophical Transactions of the Royal Society of London (B): Biological Sciences* 335(1273):11–20; discussion 20–21. [aJKO]

Rolls, E. T. & O'Mara, S. M. (1995) View-responsive neurons in the primate hippocampal complex. *Hippocampus* 5(5):409–24. [aJKO]

Ross, T. (1933) Machines that think. *Scientific American* 148:206–208. [BJS]

Rossetti, Y., Koga, K. & Mano, T. (1993) Prismatic displacement of vision induces transient changes in the timing of eye hand coordination. *Perception and Psychophysics* 54(3):355–64. [aJKO]

Rossetti, Y., Rode, G., Pisella, L., Farnè, A., Li, L., Boisson, D. & Perenin, M. T. (1998) Prism adaptation to a rightward optical deviation rehabilitates left hemispatial neglect. *Nature* 395:166–69. [PB]

Royce, J. (1885/1958) *The religious aspect of philosophy: A critique of the bases of conduct and faith.* Harper. (Original publication 1885). [EW]

Royden, C. S., Crowell, J. A. & Banks, M. S. (1994) Estimating heading during eye movements. *Vision Research* 34:3197–214. [N-GK]

Rozenblom Y. Z. & Kornyushina, T. A. (1991) Monocular diplopia. *Vcastnik Oftalmologii* 107(3):39–44. [aJKO]

Ryan, J. D., Althoff, R. R., Whitlow, S. & Cohen, N. J. (2000) Amnesia is a deficit in relational memory. *Psychological Science* 11(6):454–61. [JDR]
Ryan, J. D., & Cohen, N. J. (submitted) The nature of visual memory representations. [JDR]
Ryle, G. (1949/1990) *The concept of mind.* Penguin Books. [JB, DCD, aJKO]
Sadato, N., Pascual-Leone, A., Grafman, J., Deiber, M. P., Ibanez, V. & Hallett, M. (1998) Neural networks for Braille reading by the blind. *Brain* 121(Pt. 7):1213–29. [aJKO]
Salzman, C. D., Britten, K. H. & Newsome, W. T. (1990) Cortical microstimulation influences perceptual judgements of motion direction. *Nature* 346(6280):174–77. [GR]
Sampaio, E. (1989) Is there a critical age for using the sonicguide with blind infants? *Journal of Visual Impairment and Blindness* 83:105–108. [aJKO]
(1995) Les substitutions sensorielles adaptées aux dèficits visuels importants. In: *Le dèficit visuel. Des fondements neurophysiologiques à la pratique de la réadaptation,* ed. A. B. Assimacopoulos & A. Saffran. Masson. [aJKO]
Sampaio, E. & Dufier, J. L. (1988) Suppléance sensorielle électronique pour les jeunes enfants aveugles. *Journal Français Ophtalmologique* 11(2):161–67. [aJKO]
Saxberg, B. V. (1987) Projected fire ball trajectories. I. Theory and simulation. *Biological Cybernetics* 56:159–75. [FL]
Schachter, D. L. & Buckner, R. L. (1998) Priming and the brain. *Neuron* 20:185–95. [JDR]
Scheier, C. & Pfeifer, R. (1995) Classification as sensorimotor co-ordination: A case study on autonomous agents. In: *Advances in artificial life: Proceedings of the Third European Conference on Artificial Life,* ed. F. Moran, A. Moreno, P. Chacon & J. J. Merelo. Springer Verlag. [MS]
Schlesinger, M. & Barto, A. (1999) Optimal control methods for simulating the perception of causality in young infants. In: *Proceedings of the Twenty First Annual Conference of the Cognitive Science Society,* ed. M. Hahn & S. C. Stoness. Erlbaum. [MS]
Schlesinger, M. & Parisi, D. (2001) The agent-based approach: A new direction for computational models of development. *Developmental Review* 21:121–46. [MS]
Schlingensiepen, K.-H., Campbell, F. W., Legge, G. E. & Walker, T. D. (1986) The importance of eye movements in the analysis of simple patterns. *Vision Research* 26(7):1111–17. [aJKO]
Schmidt, T. (2000) Visual perception without awareness: Priming responses by color. In: *Neural correlates of consciousness,* ed. T. Metzinger. MIT Press. [UA]
Scholl, B. J., Simons, D. J. & Levin, D. T. (submitted) "Change blindness" blindness: An implicit measure of a metacognitive error. [BJS]
Schwab, E. C., Nusbaum, H. C. & Pisoni, D. B. (1985) Effects of training on the perception of synthetic speech. *Human Factors* 27:395–408. [HCN]
Scott-Brown, K. C., Baker, M. R. & Orbach, H. S. (2000) Comparison blindness. *Visual Cognition* 7:253–67. [BJS]
Sellars, R. W. (1919) The epistemology of evolutionary naturalism. *Mind* 28(112):407–26. [EW]
(1922) *Evolutionary naturalism.* Open Court. [EW]
(1932) *The philosophy of physical realism.* Macmillan. [EW]
Shakhnovich, A. R. & et al. (1982) Phosphene formation during electrical stimulation of the visual cortex. *Human Physiology* 8(1):34–39. [ZWP]
Sharp, R. H. & Whiting, H. T. (1974) Exposure and occluded duration effects in a ball catching skill. *Journal of Motor Behavior* 6:139–47. [FL]
Shebilske, W. L. (1977) Visuomotor coordination, visual direction and position constancies. In: *Stability and constancy in visual perception: Mechanisms and processes,* ed. W. Epstein. Wiley. [aJKO]
Shepard, R. N. (1978) The mental image. *American Psychologist* 33:125–37. [PByR]
Shinar, D. (1978) *Psychology on the road: The human factor in traffic safety.* Wiley. [N-GK]
Siewart, C. (1998) *The significance of consciousness.* Princeton University Press. [NB]
Silbersweig, D. A., Stern, E., Frith, C., Cahill, C., Holmes, A., Grootoonk, S., Seaward, J., McKenna, P., Chua, S. E., Schnorr, L. & et al. (1995) A functional neuroanatomy of hallucinations in schizophrenia. *Nature* 378(6553):176–79. [GR]
Simon, T. J. (1998) Computational evidence for the foundations of numerical competence. *Developmental Science* 1:71–78. [MS]
Simons, D. J. (1996) In sight, out of mind: When object representations fail. *Psychological Science* 7(5):301–305. [BWT]
(2000a) *Change blindness and visual memory: A special issue of the journal "Visual Cognition."* Psychology Press. [BJS]
(2000b) Current approaches to change blindness. *Visual Cognition* 7:1–16. [aJKO, BJS] Also in: *Visual cognition: Change blindness and visual memory,* ed. D. J. Simons. [Special issue of *Visual Cognition*]. Psychology Press. [JRP]
Simons, D. J. & Chabris, C. F. (1999) Gorillas in our midst: Sustained inattentional blindness for dynamic events. *Perception* 28(9):1059–74. [aJKO]
Simons, D. J., Chabris, C. F., Schnur, T. & Levin, D. T. (in press) Preserved representations in change blindness. *Consciousness and Cognition.* [BJS]
Simons, D. J., Franconeri, S. L. & Reimer, R. L. (2000) Change blindness in the absence of a visual disruption. *Perception* 29:1143–54. [BJS]
Simons, D. J. & Levin, D. T. (1997) Change blindness. *Trends in Cognitive Sciences* 1(7):261–67. [aJKO]
Singer, W. (1993) Synchronization of cortical activity and its putative role in information processing and learning. *Annual Review of Physiology* 55:349–74. [aJKO]
Singer, W. & Gray, C. M. (1995) Visual feature integration and the temporal correlation hypothesis. *Annual Review of Neurosciences* 18:555–86. [aJKO]
Small, S. L., Burton, M. W., Perfetti, C. A. & Noll, D. C. (2000) Sentence listening with and without responding. (submitted). [HCN]
Smania, N., Martini, M. C., Gambina, G., Tomelleri, G., Palamara, A., Natale, E. & Marzi, C. A. (1998) The spatial distribution of visual attention in hemineglect and extinction patients. *Brain* 121(Pt. 9):1759–70. [PB]
Smeets, J. B. J. & Brenner, E. (1994) The difference between the perception of absolute and relative motion: A reaction time study. *Vision Research* 34:191–95. [JBJS]
(1995) Perception and action are based on the same visual information: Distinction between position and velocity. *Journal of Experimental Psychology: Human Perception and Performance* 21:19–31. [JBJS]
(1999) A new view on grasping. *Motor Control* 3:237–71. [JBJS]
(2001) Action beyond our grasp. *Trends in Cognitive Sciences* 5:287. [JBJS]
Smith, K. U. & Smith, W. M. (1962) *Perception and motion.* W. B. Saunders. [aJKO]
Southall, J. P. C., ed. (1962) *Helmholtz's treatise on physiological optics. Vol. 2: The sensation of vision,* trans. J. P. C. Southall. (Translated from the third German edition). Dover. [VV]
Spelke, E. S. (1998) Nativism, empiricism, and the origins of knowledge. *Infant Behavior and Development* 21:181–200. [MS]
Sperling, G. (1960) The information available in brief visual presentations. *Psychological Monographs* 74:1–29. [JH, VAFL]
Sperry, R. W. (1952) Neurology and the mind-brain problem. *American Scientist* 40:291–311. [JH, aJKO]
Stadler, M. (1989) On learning complex procedural knowledge. *Journal of Experimental Psychology: Learning, Memory, and Cognition* 15:1061–69. [VGH]
Stelmach, L. B., Bourassa, C. M. & di Lollo, V. (1984) Detection of stimulus change: The hypothetical roles of visual transient responses. *Perception and Psychophysics* 35(3):245–55. [aJKO]
Sterr, A., Muller, M. M., Elbert, T., Rockstroh, B., Pantev, C. & Taub, E. (1998) Perceptual correlates of changes in cortical representation of fingers in blind multifinger Braille readers. *Journal of Neuroscience* 18(11):4417–23. [aJKO]
Stewart, I. (1986) Exotic structures on four-space. *Nature* 322:310–11. [EW]
Stoerig, P. (1996) Varieties of vision: From blind responses to conscious recognition. *Trends in Neurosciences* 19:401–406. [VAFL]
Stratton, G. M. (1897) Vision without inversion of the retinal image. *Psychological Review* 4:341–60; 463–81. [aJKO]
Strauch, I. & Meier, B. (1996) *In search of dreams. Results of experimental dream research.* SUNY Press. [AR]
Straus, E. (1963) *The primary world of senses.* The Free Press of Glencoe Collier-Macmillan. [UA]
Strawson, G. (1989) Red and 'red'. *Synthese* 78:194. [rJKO]
Strawson, P. F. (1974) Imagination and perception. In: P. F. Strawson, *Freedom and resentment and other essays.* Methuen. [aJKO]
Strelow, E. R. & Brabyn, J. A. (1982) Locomotion of the blind controlled by natural sound cues. *Perception* 11(6):635–40. [aJKO]
Stroud, J. M. (1955) The fine structure of psychological time. In: *Information theory in psychology: Problems and methods,* ed. H. Quastler. Free Press. [rJKO, BJS]
Stubenberg, L. (1998) *Consciousness and qualia.* John Benjamins. [RM]
Super, H., Spekreijse, H. & Lamme, V. A. F. (2001) Two distinct modes of sensory processing observed in monkey primary visual cortex (V1). *Nature Neuroscience* 4:304–10. [VAFL]
Tastevin, J. (1937) En partant de l'expérience d'aristote les déplacements artificiels des parties du corps ne sont pas suivis par le sentiment de ces parties ni par les sensations qu'on peut y produire. *L'Encéphale* XXXII(2):57–84. [aJKO]
Tatler, B. W. (2001) Characterising the visual buffer: Real-world evidence for overwriting early in each fixation. *Perception* 30(8):993–1006. [JS]
Taylor, J. G. (1962) *The behavioral basis of perception.* Yale University Press. [aJKO]
Teller, D. Y. (1984) Linking propositions. *Vision Research* 24:1233–46. [aJKO]
Teller, D. Y. & Pugh, E. N., Jr. (1983) Linking propositions in color vision. In: *Colour vision: Physiology and psychophysics,* ed. J. D. Mollon & L. T. Sharpe. Academic Press. [aJKO]
Theeuwes, J. (1991) Exogenous and endogenous control of attention: The effect of visual onsets and offsets. *Perception and Psychophysics* 49(1):83–90. [aJKO]

Thomas, N. J. (1999) Are theories of imagery theories of imagination? An active perception approach to conscious mental content. *Cognitive Science* 23(2):207–45. [JH, aJKO]

Thompson, E. (1995) *Colour vision: A study in cognitive science and the philosophy of perception.* Routledge. [aJKO]

Thompson, E., Noë, A. & Pessoa, L. (1999) Perceptual completion: A case study in phenomenology and cognitive science. In: *Naturalizing phenomenology: Issues in contemporary phenomenology and cognitive science,* ed. J. Petitot, J.-M. Roy, B. Pachoud & F. J. Varela. Stanford University Press. [aJKO]

Thompson, E., Palacios, A. & Varela, F. J. (1992) Ways of coloring: Comparative color vision as a case study for cognitive science. *Behavioral and Brain Sciences* 15(1):1–74. [aJKO]

Thompson, E. & Varela, F. J. (2001) Radical embodiment: Neural dynamics and conscious experience. *Trends in Cognitive Sciences.* (in press). [aJKO]

Thorpe, S., Fize, D. & Marlot, C. (1996) Speed of processing in the human visual system. *Nature* 381(6582):520–22. [aJKO]

Todorovic, D. (1987) The Craik-O'Brien-Cornsweet effect: New varieties and their theoretical implications. *Perception and Psychophysics* 42(6):545–60. [aJKO]

Toet, A. & Levi, D. M. (1992) The two-dimensional shape of spatial interaction zones in the parafovea. *Vision Research* 32(7):1349–57. [aJKO]

Tolhurst, D. J. (1975) Sustained and transient channels in human vision. *Vision Research* 15:1151–55. [aJKO]

Tong, F., Nakayama, K., Vaughan, J. T. & Kanwisher, N. (1998) Binocular rivalry and visual awareness in human extrastriate cortex. *Neuron* 21(4):753–59. [GR]

Tresilian, J. R. (1993) Four questions of time to contact: A critical examination of research on interceptive timing. *Perception* 22:653–80. [FL]

(1999) Visually timed action: Time-out for 'tau'? *Trends in Cognitive Sciences* 3:301–10. [FL]

Treue, S. & Maunsell, J. H. R. (1996) Attentional modulation of visual motion processing in cortical areas MT and MST. *Nature* 382:539–41. [aJKO]

Tulving, E. & Schacter, D. L. (1990) Priming and human memory systems. *Science* 247(4940):301–306. [JDR]

Turvey, M. T., Shaw, R. E., Reed, E. S. & Mace, W. M. (1981) Ecological laws of perceiving and acting: In reply to Fodor and Pylyshyn (1981). *Cognition* 9(3):237–304. [aJKO]

Uchikawa, K. & Sato, M. (1995) Saccadic suppression of achromatic and chromatic responses measured by increment-threshold spectral sensitivity. *Journal of the Optical Society of America (A)* 12(4):661–66. [aJKO]

Ullman, S. (1979) *The interpretation of visual motion.* MIT Press. [ZWP]

(1980) Against direct perception. *Behavioral and Brain Sciences* 3:373–415. [BJS]

Umiltà, M. A., Kohler, E., Gallese, V., Fogassi, L., Fadiga, L., Keysers, C. & Rizzolatti, G. (2001) "I know what you are doing": A neurophysiological study. *Neuron* 31:155–65. [VG]

Ungerleider, L. G. & Mishkin, M. (1992) Two cortical visual systems. In: *Analysis of visual behavior,* ed. D. J. Ingle, M. A. Goodale & R. J. W. Mansfield. MIT Press. [aJKO]

Uusitalo, M. A., Virsu, V., Salenius, S., Näsänen, R. & Hari, R. (1997) Activation of human V5 complex and rolandic regions in association with moving visual stimuli. *Neuroimage* 5:1053–59. [VV]

Vanni, S., Portin, K., Virsu, V. & Hari, R. (1999) Mu ryhthm modulation during changes of visual percepts. *Neuroscience* 91:21–31. [VV]

Vanni, S., Revonsuo, A. & Hari, R. (1997) Modulation of the parieto-occipital alpha rhythm during object detection. *The Journal of Neuroscience* 17:7141–47. [VV]

Vanni, S., Revonsuo, A., Saarinen, J. & Hari, R. (1996) Visual awareness of objects correlates with activity of right occipital cortex. *NeuroReport* 8:183–86. [VV]

Varela, F. J. (1984) *Living ways of sense-making. A middle path for neuroscience.* Paper presented at the disorder and order symposium: Proceedings of the Stanford International Symposium. [aJKO]

Varela, F. J. & Shear, J. (1999) The view from within. *Journal of Consciousness Studies* 6(2/3):293–96. [aJKO]

Varela, F. J., Thompson, E. & Rosch, E. (1991) *The embodied mind: Cognitive science and human experience.* MIT Press. [aJKO]

Vega-Bermudez, F. & Johnson, K. O. (1999) SA1 and RA receptive fields, response variability, and population responses mapped with a probe array. *Journal of Neurophysiology* 81(6):2701–10. [EN]

Velichkovsky, B. M., Luria, A. R. & Zinchenko, V. P. (1973) *Psychologia vospriatia* [*Psychology of perception*]. Moscow University Press. [BMV]

Verfaillie, K. & De Graef, P. (2000) Transsaccadic memory for position and orientation of saccade source and target. *Journal of Experimental Psychology: Human Perception and Performance* 26:1243–59. [PDG]

Virsu, V. & Hari, R. (1996) Cortical magnification, scale invariance, and their biology. *Vision Research* 36:2971–77. [VV]

von der Heydt, R. & Peterhans, E. (1989) Mechanisms of contour perception in monkey visual cortex. I. Lines of pattern discontinuity. *Journal of Neuroscience* 9(5):1731–48. [aJKO]

von der Heydt, R., Peterhans, E. & Baumgartner, G. (1984) Illusory contours and cortical neuron responses. *Science* 224(4654):1260–62. [aJKO]

von der Malsburg, C. (1983) How are nervous structures organized? In: *Synergetics of the brain,* ed. E. Basar, H. Flohr, H. Haken & A. J. Mandell. Springer. [aJKO]

von Melchner, L., Pallas, S. L. & Sur, M. (2000) Visual behaviour mediated by retinal projections directed to the auditory pathway. *Nature* 404:871–76. [aJKO]

Vuilleumier, P., Sagiv, N., Hazeltine, E., Poldrack, R., Rafal, R. & Gabrieli, J. (2001) The neural fate of seen and unseen faces in visuospatial neglect: A combined event-related fMRI and ERP study of visual extinction. *Proceedings of the National Academy of Sciences USA* 98:3495–500. [GR]

Wagemans, J. & de Weert, C. M. M. (1992) Ways of coloring the ecological approach. *Behavioral and Brain Sciences* 15(1):54–56. [aJKO]

Walker, R., Deubel, H., Schneider, W. X. & Findlay, J. M. (1997) Effect of remote distractors on saccade programming. *Journal of Neurophysiology* 78:1108–19. [BMV]

Wall, J. T., Kaas, J. H., Sur, M., Nelson, R. J., Felleman, D. J. & Merzenich, M. M. (1986) Functional reorganization in somatosensory cortical areas 3b and 1 of adult monkeys after median nerve repair: Possible relationships to sensory recovery in humans. *Journal of Neuroscience* 6(1):218–33. [aJKO]

Warren, D. H., Welch, R. B. & McCarthy, T. J. (1981) The role of visual-auditory "compellingness" in the ventriloquism effect: Implications for transitivity among the spatial senses. *Perception and Psychophysics* 30(6):557–64. [aJKO]

Warren, R. M. (1970) Perceptual restoration of missing speech sounds. *Science* 167:392–93. [FI]

Warren, W. H. (1995) Self motion: Visual perception and visual control. In: *Perception of space and motion,* ed. W. Epstein & S. Rogers. Academic Press. [N-GK]

Watson, J. S., Banks, M. S., von Hofsten, C. & Royden, C. S. (1992) Gravity as a monocular cue for perception of absolute distance and/or absolute size. *Perception* 21:69–76. [FL]

Weber, H., Dürr, N. & Fischer, B. (1998) Effects of pre-cues on voluntary and reflexive saccade generation. II. Pro-cues for anti-saccades. *Experimental Brain Research* 120:417–31. [BF]

Weiskrantz, L. (1986) *Blindsight: A case study and implications.* Oxford University Press. [aJKO]

(1997) *Consciousness lost and found: A neuropsychological exploration.* Oxford University Press. [aJKO]

Welch, R. B., Bridgeman, B., Anand, S. & Browman, K. E. (1993) Alternating prism exposure causes dual adaptation and generalization to a novel displacement. *Perception and Psychophysics* 54(2):195–204. [aJKO]

White, J. C., Saunders, F. A., Scadden, L., Bach-y-Rita, P. & Collins, C. C. (1970) Seeing with the skin. *Perception and Psychophysics* 7:23–27. [aJKO]

Whitney, D. & Murakami, I. (1998) Latency difference, not spatial extrapolation. *Nature Neuroscience* 1:656–57. [JBJS]

Wolfe, J. M. (1997) Visual experience: Less than you think, more than you remember. In: *Neuronal basis and psychological aspects of consciousness,* ed. C. Taddei-Ferretti. World Scientific. [aJKO]

(1999) Inattentional amnesia. In: *Fleeting memories,* ed. V. Coltheart. MIT Press. [aJKO]

Wolfe, J. M., Klempen, N. & Dahlen, K. (2000) Post-attentive vision. *Journal of Experimental Psychology: Human Perception and Performance* 26(2):693–716. [PDG, aJKO, JDR]

Wolpert, D. M. (1997) Computational approaches to motor control. *Trends in Cognitive Sciences* 1:209–16. [VG]

Wolpert, D. M., Ghahramani, Z. & Jordan, M. I. (1995) An internal model for sensorimotor integration. *Science* 269:1880–82. [VG]

Worchel, P., Mauney, J. & Andrew, J. (1950) The perception of obstacles by the blind. *Journal of Experimental Psychology* 40:746–51. [aJKO]

Wright, E. L. (1975) Perception: A new theory. *American Philosophical Quarterly* 14(4):273–32. [EW]

(1983) Inspecting images. *Philosophy* 58(223):51–72. [EW]

(1990) New representationalism. *Journal for the Theory of Social Behaviour* 20(1):65–91. [EW]

(1992) The entity fallacy in epistemology. *Philosophy* 67(259):33–50. [EW]

(1994) A new critical realism: An examination of Roy Wood Sellars' epistemology. *Transactions of the C. S. Pierce Society* 30(3):477–514. [EW]

(1996) What it isn't like. *American Philosophical Quarterly* 33(1):23–42. [EW]

(1999) The game of reference. In: *Connectionism and the philosophy of psychology,* ed. M. Potrc. *Acta Analytica* 22. [EW]

(2000) The Joke, the "As If" and the Statement. In: *The analytic Freud,* ed. M. Levine. Routledge. [EW]

(2001) Faith and the real. In: *Slavoj Zizek: Faith and the real,* ed. E. Wright. *Paragraph* 24:5–22. [EW]

Wynn, K. (1992) Addition and subtraction by human infants. *Nature* 358:749–50. [MS]

Yantis, S. (1998) Control of visual attention. In: *Attention,* ed. H. Pashler. Psychology Press/Erlbaum/Taylor & Francis. [aJKO]

Yap, Y. L., Levi, D. M. & Klein, S. A. (1989) Peripheral positional acuity: Retinal and cortical constraints on 2-dot separation discrimination under photopic and scotopic conditions. *Vision Research* 29(7):789–802. [aJKO]

Zatorre, R. J., Evans, A., Meyer, E. & Gjedde, A. (1992) Lateralization of phonetic and pitch discrimination in speech processing. *Science* 256:846–49. [HCN]

Zeki, S. (1993) *A vision of the brain.* Blackwell. [aJKO]

Zihl, J., von Cramon, D. & Mai, N. (1983) Selective disturbance of movement vision after bilateral brain damage. *Brain* 106(Pt 2):313–40. [GR]

Zipser, D. & Anderson, R. (1988) A back-propagation programmed network that simulates response properties of a subset of posterior parietal neurons. *Nature* 331:679–84. [aJKO]