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Part III

EMPIRICAL DEVELOPMENTS

CHAPTER 11

Situated Perception and Sensation in Vision and Other Modalities

A Sensorimotor Approach

Erik Myin and J. Kevin O'Regan

Voir un objet, c'est ou bien l'avoir en marge du champ visuel et pouvoir le fixer, ou bien répondre effectivement à cette sollicitation en le fixant. Quand je le fixe, je m'ancre en lui, mais cet 'arrêt' du regard n'est qu'une modalité de son mouvement: je continue à l'intérieur d'un objet l'exploration qui, tout à l'heure, les survolait tous.

Maurice Merleau-Ponty, 1945

1. Introduction

Seeing and perceiving are not achievements of an isolated head or brain, quietly humming about on its own. The organism moves its eyes, repositions its body to get a better perceptual grip on the objects that surround it, and thereby attempts to advance in the execution of the hierarchy of ongoing projects it is engaged in. The locus of perceptual processing includes the world rather than being just confined to the head. In the case of vision, at any moment, only the precise information that is needed at that moment is sought by moving the eye, the body, or by shifting attention to where in the world this information is to be found.

In this chapter, we will set out how an account of vision in which the world is considered to form an external memory allows for explanation of the experienced continuity of vision. We will show how the hypothesis of the world as an outside memory is supported by findings in the change and attentional blindness paradigms, as well as by the study of vision in action.

Then we turn to the sensorimotor contingency approach to sensation and perception in general. Here, as in the hypothesis of the world as an outside memory, the explanatory load for understanding the character of sensory experience is put on the precise ways in which an organism perceptually interacts with its environment. We present recent empirical research from the sensorimotor perspective, and end by pointing out how a sensorimotor account provides the possibility of explaining how perception differs from thought.

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2. The Visual Field and the World as an Outside Memory

2.1. *Continuity in Experience*

What do you see when you see? Different things at different times, of course, but your visual experience almost always has the character of a seen scene. You see an expanse of objects and backgrounds, with their shapes, colors, and motions, which stretches out from a certain extent to your left, to a certain extent to your right, as well as up and down. It certainly appears to us as if what is often called our "visual field" is spatially continuous in the sense that everything in it is seen in roughly the same way. Things to the side of what you are most pointedly looking at, even if at the periphery, surely seem seen, and they have the same visual characters (e.g., shape, color, motion) as that which you directly look at.

Consider your current visual experience as you are reading this page. Don't you see the whole page, book, or even part of your hands or the desk that is supporting it – even if you are only reading part of the text at each moment? And aren't the pages sprayed with what is definitively text – in regular format?

Corollary to this spatial continuity, vision also seems temporally continuous. The contents of the visual field change frequently, but, unless we close our eyes, the field remains continually present.

Yet temporal continuity loses its aura of evidence when confronted with the mundane observation that we blink every few seconds. Why doesn't this lead to an interruption of visual experience – as happens when we are in a room in which the light goes out from time to time? Worse than blinks, eye movements create displacements of the retinal image at a rate of about three to five times a second all the waking day. One might think that we should see our world continually jumping around. Why don't we?

2.2. *Anatomical Discontinuity*

There not only would appear to be a problem in explaining the perceived temporal continuity of the world, but anatomical factors pose problems concerning the world's apparent spatial continuity.

First of all, the retina is not a uniform sensor: photoreceptors are arranged in a nonhomogeneous fashion, most closely spaced at the center of the fovea, with spacing increasing linearly all the way through the fovea and out to about ten to fifteen degrees in periphery. The type of receptor also changes as you move out into the periphery, with cones being in the majority up to about five degrees, and then rods taking over as the main receptor type further out in periphery. A second curious fact about the retina is the fact that it is inverted, with the axons and blood vessels that irrigate it placed on the anterior surface; that is, facing the light. This means that shadows of these structures obscure the light-sensitive surface. In one particular place on the retina, the axons and blood vessels come together to leave the eyeball where they form the optic nerve. At this location about ten to fifteen degrees on the nasal side of each eye there can be no photoreceptors and there is a scotoma, or blind spot, whose approximate six-degree projection in the visual field is sufficient to engulf an orange held at arm's length. And yet despite these defects of the eye's receptor surface, we do not see spatial nonhomogeneities in our visual fields.

Another curious fact concerns the optics of the eye. Compared to even a low-cost camera, the eye's lens lacks surprisingly in quality. Chromatic aberration creates a difference of about 1.6 diopters in the focal length for red and blue light – meaning that the eye cannot simultaneously focus features of different colors. Spatial distortions due to imperfections in the lens shape and to the sphericity of the eyeball are also significant outside the foveal zone.

It is striking, however, that none of these anatomical particularities are reflected in the experienced phenomenal field. If they were, we would experience our visual field not only as inverted but also as having a small central region in full color and detail and a blurred surround in drained colors.

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But of course the visual field does not appear to us that way. Instead it looks smooth and roughly continuous: with things in it seen in roughly the same way all over. How is this possible? How can our experience have the continuity it has despite what seem like grave defects in the anatomy?

2.3. *The Hypothesis of the World as an Outside Memory*

To begin to answer this question, consider the light in a refrigerator (Thomas, 1999). Unless we knew better, we would believe that the refrigerator's light is always on. Indeed, whenever we open the door to look at it, it is on. It seems continuously on, not because it is always on, and certainly not because we continuously see it as being on, but because it is on whenever we look.

In a similar vein, we suggest, the scene we are confronted with seems to be detailed, not because we see all of the details all of the time but because we find the details whenever we look for them.

That is, the elements of the scene that are in peripheral vision or are currently not attended to are seen only in a secondary sense. The retina registers these elements, but we do not see them fully as we see something we attend to. Only when we turn to them and scrutinize them, do we actually see all the detail.

Our sense of seeing everything all at once is greatly enhanced by the property we call "grabbiness." Grabbiness refers to the fact that the visual system is so wired that visual transients – sudden changes in visual stimulation (e.g., those arising from a sudden motion or a sudden change in color) – generally trigger a jump of the eye so as to bring the fovea in line with it. This means that normally a significant visual change in the scene will be immediately recognized and scrutinized. Grabbiness supports our feeling of visually experiencing the whole scene because it, normally, ensures that no significant change in visual properties escapes our notice. What better evidence could one have that one is fully and continually seeing something than the fact that one notices whenever it changes?

In which sense is our pretheoretical understanding of seeing as continuous wrong and in which sense is it right? It is wrong to the extent that in a certain sense we do not really fully see all the detail at any moment; in fact, seeing is sequential rather than continuous.[1] It is right in that in some sense we still do actually see it!

The approach we propose can be called the hypothesis of the world as an outside memory, following O'Regan (1992), because of the emphasis on the fact that it is the world itself, rather than some internal memory store, that is continually interrogated and dealt with.

So, the apparent contradiction between the smoothness of experience and the apparent defects of our retinas can be avoided by understanding the active nature of vision, and by realizing that no internal replica of the world needs to be reconstructed inside the brain to account for every feature of awareness. For example, the very strong nonhomogeneity of retinal sampling, with resolution dropping off drastically for every degree we move out into peripheral vision, the poor optical quality of peripheral vision and the lack of color-sensitive cones in periphery do not give us the phenomenal feel of a poor-quality, out-of-focus, monochrome world in our peripheral fields. Again, the reason is that we do not see the retina: we see the world, as probed by the retina, which we use as a tool. This is analogous to what happens when we feel a table through tactile exploration: we do not feel our hands and their imperfections – gaps, fingernails, differences in tactile resolution – rather, we feel the table by using our hand as a tool. We do not think there are gaps in the tabletop where there are gaps between our fingers. This is presumably not because we have a gap-filling-in mechanism to compensate the gaps but because feeling the table does not consist in exhaustively scanning the table to re-create inside the head a kind of internal model. Rather, feeling the table is an ongoing exploratory activity in which we can instantaneously access any information

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we require by displacing our hand. In the same way, in vision, eye movements and attention changes can instantaneously provide any information that may be necessary about objects in the visual field. As MacKay suggested (1962, 1967, 1973), the retina is like a giant hand that can be moved over the scene.

3. Change Blindness

An interesting empirical prediction follows from the hypothesis of the world as an outside memory. Under this view, the impression of seeing everything in the visual field in front of us derives not from all the detail actually being continuously represented in the brain, but from its immediate accessibility at the mere flick of the eye or of attention. If this is true, then large changes in an image should surely go unnoticed when these occur on parts of the image that are not currently part of what the viewer is visually exploring.

The problem is that this prediction cannot be tested under normal circumstances because of the grabbiness we have just described: usually changes in an image provoke rapid motion signals and contrast-change signals in the low-level visual system that immediately grab the viewer's attention. If it were possible to prevent such transients from occurring, or to somehow mask them, then, under the view of the world as an outside memory, the changes should not be noticed (unless by chance the viewer happened to be scrutinizing the very location that changed).

These ideas were the motivation for the paradigm of change blindness that O'Regan, Rensink, and Clark (1999) and Rensink, O'Regan, and Clark (1997, 2000) introduced. In this paradigm a large change in an image is made but a brief flicker or "mud splash" is simultaneously superimposed on the screen (see Figure 11.1). This produces transients all over the image that drown out the local transient that corresponds to the true image-change location. Another effective way to prevent the attention-grabbing action of local transients is to make them occur extremely slowly (see Auvray & O'Regan, 2003; Simons, Franconeri, & Reimer, 2000). The results of all these experiments confirm the following: unless observers happen to be scrutinizing the changing location as the change occurs, they tend to miss the change.

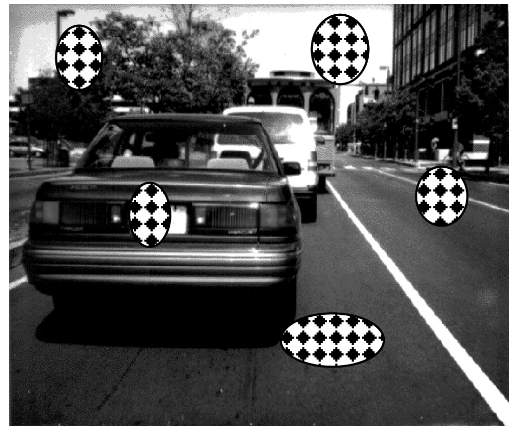

Figure 11.1. Example of the mud-splash phenomenon (O'Regan, Rensink, & Clark 1999). If the five patterned ellipses (mud splashes) appear very briefly and disappear at the same time as a large change in the picture (e.g., the solid white line in the street becomes a dashed line), this will often not be noticed. For other demonstrations of change blindness, see http://nivea.psycho.univ-paris5.fr.

The change blindness paradigm has generated much research (c.f. Simons & Rensink, 2005) and can be observed in a variety of other situations (when the image change occurs during eye saccades, eye blinks, cuts in a film sequence, or even in candid-camera type situations in everyday life; cf. Simons & Levin 1997). It is a direct prediction of the idea of the world as an outside memory. It was discovered following elaboration of that idea, and it can be considered striking empirical support for the theory.

Further empirical confirmation of the idea that we do not continually represent the entire visual field in all its richness comes from the inattentional blindness paradigm (see Mack & Rock, 1998; Simons & Chabris, 1999). In this it is shown that when observers are intently engaged in a task like following

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a ball in a complex scene, they can fail to notice a totally obvious and striking event occurring right before their eyes, such as a person dressed in a gorilla outfit passing through the scene. Phenomena like this are, in fact, well known as "looked but failed to see" errors in ergonomics, where it has been observed that vehicle drivers frequently collide with obstacles that they are directly looking at (e.g., trains passing by at railway crossings, police cars stopped by the side of the road, bicycles passing directly in front of them, airplanes parked in the middle of the runway; see Herslund & Jorgensen, 2003; Hills, 1980; Langham, Hole, Edwards, & O'Neil, 2002). They show again the importance of attentive exploration of the scene for there to be awareness of its contents. This further bolsters the hypothesis of the world as an outside memory.

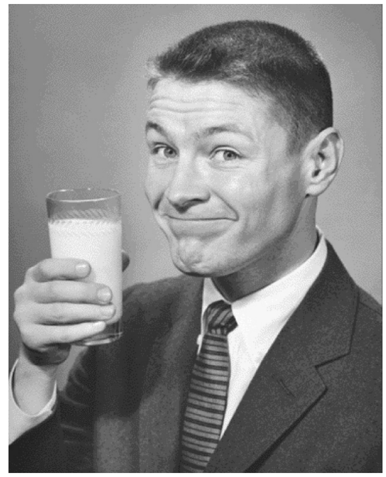

Figure 11.2. Example from Rensink, O'Regan, and Clark (1997) in which a change in the size of the glass of milk is generally noticed immediately because this is a central interest part of the picture.

4. Clarification Concerning Representations

It is important to point out exactly how the hypothesis of the world as an outside memory offers a different explanation of the experience of visual continuity from that of the more traditional representational account.

What the hypothesis denies is not the general claim that there are representations operative in one or various stages of visual processing but that the feeling of seeing all the detail at any moment is the result of a fully detailed, continuously present representation of all the detail.[2]

What change blindness highlights, according to the hypothesis of the world as an outside memory, is the falseness of the idea that you see all the detail at any moment. Regions that are seen peripherally, or that are not attended to, are not seen in detail. If they were so, you would see the changes. Indeed, in the change blindness paradigm exposure, if you happen to be focusing on or attending to the elements to which the changes occur, you do see the changes. If the change occurs in the thematically central element of the scene, you do not fail to notice it, despite an inserted blank screen (Rensink et al., 1997) or the presence of mud splashes (see Figure 11.2; O'Regan et al., 1999).

Because you do not fully see the peripheral or unattended details, it seems pointless to try to account for their being seen via a fully detailed representation. Rather, what should be given an explanation is the pretheoretical conviction that we nevertheless see everything continually. Such an explanation is precisely what is provided for in the approach of the world as an outside memory: you think you see all the detail at any moment not because you actually see it continuously but because you see detail whenever you care about detail – remember the refrigerator light.[3]

Thus, no detailed representation is necessary to account for visual awareness according to the world-as-an-outside-memory hypothesis, which provides a simpler account without such a detailed representation and is in accordance with data from visual anatomy. It leads to correct predictions for the phenomenon of change blindness. Further evidence for the hypothesis can be found in the study of vision in the context of activities such as reading,

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playing a ball game, or solving a visual problem, which will be reviewed in the next section.

5. Vision in Action

Data obtained by studying vision in natural conditions have highlighted features that are strongly supportive of the hypothesis of the world as an outside memory. In particular, such studies have indicated the large degree to which seeing is the following:

- Economical or sparse, in the sense that, at successive moments of visual activity, only a very small part of a scene is actually being processed
- Task dependent, or specifically adapted to the ongoing project, because what is looked at is that about which information is currently needed to support one's current activity
- On-line and on-demand, which means that visual processing happens at the moment the object or part of the scene of interest is attended to

For example, in reading, though eye movements follow a general reading-specific pattern, they are influenced by specifics of the text being read (cf., e.g., O'Regan, 1990; Rayner, 1998). General features of eye movements in reading are a sequence of forward-going saccades with length seven to nine letter spaces, to a certain extent independent of font size, with occasional backward-going regressions. Saccades are separated by eye fixations with durations of about 150 ms to 350 ms. Saccade lengths and fixation durations are determined by a number of factors, ranging from low level to high level. Thus, whereas there is clearly an ongoing reading rhythm or strategy (O'Regan, 1990; Vitu, 1999, 2003; Yang & McConkie, 2001, 2004), ongoing cognitive processing at the fixation location clearly affects the precise eye-movement scanning parameters, at least on a temporal scale extending over two or three fixations (Rayner, Sereno, & Raney, 1996). For example, more difficult words tend to require more numerous or longer-duration fixations, and word-skipping tactics may be influenced by local moment-to-moment lexical, syntactic, or semantic processing (Reichle, Rayner, & Pollatsek, 2003; Reilly & Radach, 2003). This suggests that text processing occurs to some extent in an on-line fashion, at the locus of fixation, instead of being carried out on the basis of information stored in a cumulative visual buffer. This is further evidenced by the fact that changes made to the text during a fixation affect both the duration of the current fixation and the size of the subsequent saccade (Rayner, 1998).

Although the seven- to nine-letter span covered by saccades is sampled by foveal vision, some general information (e.g., word-boundary information) in a span up to about fourteen letter spaces from the fixation point affects the reading process (Rayner, 1998). Interestingly, and very telling, changes outside the fourteen-letter span have virtually no effect on processing or on the reader's awareness. So subjectively there is no difference between a reader in front of a computer screen in which changes in peripheral text areas is synchronized with the reader's gaze changes and that same reader in front of a regular, static, text-filled screen. Thus, vision in reading is sparse: readers are, at any moment, only effectively visually in touch with a small part of the environment – in this case, essentially the seven- to nine-letter portion of the page or screen that is currently being processed. Note that, nevertheless, as emphasized earlier, the experienced visual field covers significantly more.

Studies of visual exploration during everyday activities such as making tea (Land, Mennie, & Rusted, 1999) or preparing a sandwich (Hayhoe, 2000) confirm this conception of vision as very much an on-line activity, which, through its task dependence, is sparse. Invariably such studies have found that the gaze is almost uniquely directed to the objects relevant to the task (e.g., the kettle, its lid, the tap, and the stove), and that objects are looked at in serial order, roughly as long as it takes to manually deal with the

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object. Several saccades (up to eleven for the initial visual manipulation of the kettle) can be made to (different parts of) the same object. In the tea-making study, the overall structure of gaze dynamics and the number of fixations to different objects were found to be similar across subjects. In the sandwich- and tea-making studies, the functionality and economy of looking is conspicuous. For example, it was found out that the number of task-irrelevant objects viewed was less than 19 percent, and often as less than 5 percent (Land, 2004).

Investigations of seeing in steering (Land & Lee, 1994) and ball-game playing (Land & McLeod 2000) have shown that subjects direct their gaze at the richest source of relevant information. In steering on a winding road, for example, a driver will look (i.e., fixate) ahead at the tangent point on the upcoming bend; the batsman in cricket will look at the place where the ball is expected to bounce. In both cases, these points are most informative with respect to the action the subject is about to undertake (turning the steering wheel, returning the ball). In the former case, this is so because the angle between the line of sight and the tangent point corresponds to the angle to which the steering wheel has to be turned to keep the car on the road; in the latter case, it is because knowing about the location where the bouncing ball hits the ground disambiguates a previously multiply interpretable input and allows thus for prediction of precisely where the ball will be at a point optimal for the returning shot (Land & Furneaux, 1997).

In driving, other relevant cues, especially the car's position relative to the nearer parts of the road (as opposed to the more distant tangent point) are continually monitored by peripheral vision. This is shown by the fact that tampering with this source of information results in the driver's holding the road position less accurately (for further data and discussion, see Land, 2004).

Similar findings were reported in a well-known study of eye movements in a manipulative task, described in Ballard, Hayhoe, Li, and Whitehead (1992) and Ballard, Hayhoe, Pook, and Rao (1997). Here subjects were given the task of copying a pattern of colored blocks shown on a computer screen, using a resource of similar blocks in no particular order shown next to it. Using a mouse, subjects could pick up, drag, and drop blocks from the resource area to create the copy in a work space. Eye movements and mouse manipulations were continually monitored. A typical sequence of fixations and actions was as follows:

1. A fixation at a block in the model
2. A fixation at a block in the resource area that matches the color
3. Picking it up
4. A fixation at the block in the model (again)
5. A fixation at the corresponding place in the resource area
6. Dragging and dropping of the chosen block

This work of Ballard and colleagues once more testifies to the task-oriented, on-demand character of saccade dynamics. This comes out most clearly in the fact that the amount of visual information taken in appeared to be minimal, determined only by the current task demands. Thus, instead of remembering a block's color and location, most of the time subjects revisited a block to find out about its destination location after previously having been at the same block to check for its color. In other words, the world serves as an outside memory.[4]

6. The Sensorimotor Approach

We have described how the hypothesis of the world as an outside memory the accounts for the continuity of vision by emphasizing a particular way a seer interacts with his or her environment. Indeed, relative to a traditional representational account, the explanatory load for the continuity of visual experience shifts from the internal (what is in the head) to the external: the temporally spread interaction of a perceiver with his or environment.

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In the sensorimotor contingency approach to sensation and perception, this shifting of the explanatory load is carried further and applied across the board. According to this approach, the perceived quality of sensory stimulation is determined by the particular way subjects interact with their surroundings rather than by the specific character of any intervening brain processes or representations.

In the sensorimotor contingency theory, the experienced quality of perceptual feelings is taken to arise from the precise ways in which one perceptually explores one's environment. Sensorimotor contingencies (a term borrowed from MacKay, 1962) are the ways in which, during such an exploration, perceptual input varies as a function of perceptual exploratory actions.[5]

Consider the tactile perception of the softness of a sponge (O'Regan, Myin, & Noë, 2005a, 2005b). According to the sensorimotor approach, perceiving the softness of the sponge derives from regularities such as the fact that if one presses, the sponge yields. If one manually explores an object and finds that such sensorimotor interactions hold, one perceives softness. If one would detect that on pressing there is strong resistance, one perceives hardness.

In the following sections, we will consider some consequences of this view, as concerns perception of space, position, color, as well as sensory modality.

6.1. *An Example: Felt Location*

When there is tactile stimulation of the body, the location where it is experienced is usually thought to be the result of activation of a cortical map in the brain corresponding to that location. Although the sensorimotor approach accepts that such cortical activation occurs and is necessary for the sensation of local touch to occur, the approach questions the explanatory weight that the activation itself carries. Under the sensorimotor approach, the sensation of location does not arise because of activation in a cortical map per se. Instead, it arises because, by this activation, a particular assembly of potentialities for action become available; namely, the assembly of action potentialities that corresponds to the felt position. For example, if someone taps my leg, the sensation is perceived on my leg and not on my foot because moving my leg, but not my foot, can cause the sensation to change. The sensation is also perceived on my leg because I can touch my finger to that location and create a similar feeling to the one that I am currently feeling. Furthermore, I can move my eyes to the location on my leg and see the person tapping, whereas if I move my eyes to other parts of my body, I do not see the person tapping.

It is worth mentioning that as regards the notion of location, the conception of the sensorimotor approach is related to Poincaré's (1905) conception of space as intimately connected with action: the measure of the position of an object is constituted by the sequence of actions that I can potentially undertake to reach it. Philipona, O'Regan, and Nadal (2003) and Philipona, O'Regan, Nadal, and Coenen (2004) have indeed shown how an organism can infer the notion of three-dimensional space from sensorimotor contingencies. By studying the laws that determine how sensory input changes as a function of actions, an organism can discover which bodily actions produce the different types of translations and rotations in the world it inhabits, and thereby find out about spatial structure in general. It can do this without knowledge of the neural code that codes its sensory inputs or motor outputs – in fact, it can do this without knowing from what kind of sensors it is getting sensory input, and even without knowing which neural signals are sensory and which are motor.

6.2. *The Rubber Arm Experiment*

The rubber arm experiment of Botvinick and Cohen (1998) provides excellent confirmation of these ideas. Precursors of the experiment have been known since Aristotle, and more recently Tastevin (1937). The principle has been put to use by Ramachandran and Rogers-Ramachandran (2000) in

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the rehabilitation of chronic phantom-limb pains.

The subject sits with his or her hand lying on a table. The hand is hidden from the subject's view by an opaque screen. Instead of his own hand, the subject sees a rubber replica, also in front of him on the table. The experimenter taps, touches, and moves the fingers of the rubber hand while the subject watches. At the same time, the experimenter exactly replicates his or her actions on the subject's real hand behind the screen. He takes care to make the manipulation synchronous on the real and the rubber hand.

After about two minutes the rubber hand illusion occurs: subjects have the distinct feeling that the rubber hand is their own hand. This first result, already demonstrated by Botvinick and Cohen (1998), shows that the sense of ownership and felt position of a tactile stimulation is modified very rapidly by correlations between visual and tactile stimulations. This is expected from the sensorimotor theory, because by definition what is meant by the experience of location at a body position is, among other things, the fact that tactile stimulation at that location will be correlated with visual changes occurring when the eyes are directed at the location. A number of authors have confirmed that, when stimulation of rubber and real hand is asynchronous, the illusion does not occur, as expected from sensorimotor theory (e.g., Tsakiris & Haggard, 2005).

Cooke and O'Regan (2005) also examine what happens when the rubber hand is bigger or rather smaller than the subject's hand. After the illusion sets in, the experimenter asks the subject to close his eyes and to attempt to touch his thumb and index finger to two points that are marked on the table in front of him, in a sort of pincer motion. It is observed that in the synchronous condition, the size of the pincer motion is strongly affected. When the rubber hand is smaller than the subject's hand, the pincer motion is too large. When the rubber hand is larger than the subject's hand, the pincer is too small. This is consistent with the possibility, expected in the sensorimotor theory, that the subject's perceived hand size is modified by the visual-tactile correlations that he observes in the immediately preceding stimulation phase.

6.3. *Sensory Quality and Sensory Substitution Experiments*

An obvious experimental prediction of the sensorimotor theory is that it should be possible to create substitution of one sense modality by another. It should, for example, be possible to obtain a visual sensory experience through auditory input. This is predicted because the theory claims that a particular sensory experience does not derive directly from the neural channels that are involved in transmitting the information but from the sensorimotor laws that link input to output. A visual stimulation is one that obeys certain laws that are typical of the visual modality: the stimulation changes drastically when one blinks, it is modified in precise ways when one approaches or recedes from an object, information from objects can be interrupted by other objects occluding them, and so on. Auditory stimulation, for example, obeys other laws: the stimulation is not affected by blinks but by head movements. Sound sources do not occlude one another in the way visual sources occlude one another, and so on. If one were able, for example, to recreate the laws usually associated with seeing but in the auditory modality, then one should, according to the sensorimotor theory, be able to see through one's ears.

The idea of sensory substitution is not new, and it had been experimented with by Paul Bach-y-Rita and collaborators as early as the 1950s, with the tactile visual sensory substitution device (Bach-y-Rita, 1967, 1972; Bach-y-Rita, Collins, Saunders, White, & Scadden, 1969). This device converted a video image into a tactile stimulation on a twenty-by-twenty matrix of vibrators that a blind person, for example, could wear on his or her abdomen. For technical reasons, among others, the work is only gradually coming to fruition. Today a number of sensory substitution devices are being perfected and put to use to transform from

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one sensory modality to another (cf. Bach-y-Rita & Kercel, 2003). For reasons related to the feasibility of creating devices that can translate the very high spatial resolution of the human eye into another sense modality, visual substitution devices are only partly effective. Nevertheless, there are blind people who use them regularly and report that in some sense they see with these devices (Apkarian, 1983; Guarniero, 1974). Devices that convert between other modalities are also being developed. Some that convert vision into sound are moderately successful (Arno et al., 2001; Cronly-Dillon, Persaud, & Gregory, 1999; Cronly-Dillon, Persaud, & Blore 2000; Meijer, 1992; see also an evaluation of this latter device in Auvray, Hanneton, & O'Regan, 2007). The question of whether observers can really experience the existence of an outside world with such devices has been investigated with varying results (Auvray, Hanneton, Lenay, & O'Regan, 2005; Epstein, Hughes, Schneider, & Bach-y-Rita, 1986). A particularly successful device is one that allows patients with vestibular lesions to regain their sense of balance. Here an accelerometer is coupled to a tongue-display unit that delivers stimulation to a twelve-by-twelve matrix of electrodes worn on the tongue (Tyler, Danilov, & Bach-y-Rita, 2003). The tongue-based device has also been used for vision (Bach-y-Rita, Kaczmarek, Tyler, & Garcia-Lara, 1998; Sampaio, Maris, & Bach-y-Rita, 2001).

6.4. *The Sensory Quality of Color*

A major challenge for a sensorimotor theory of sensation is the problem of color, as it is difficult at first to envisage how the experience of, say, a flash of red light, could in any way be conceived of as involving a sensorimotor interaction. There would appear to be no exploratory behavior in color perception that might be analogous to pressing the sponge.

Yet given the advantage of taking the sensorimotor approach, it is worthwhile to try to find some way to apply the approach to color. The fact that it is possible to do this has recently been demonstrated, with surprising success, by Philipona and O'Regan (2006). The idea is to propose that color should not be conceived of as resulting from activation of color channels in the brain. Instead, perceiving color is a perceptual interaction that involves monitoring the way colored surfaces change incoming light into outgoing light. As one moves a red piece of paper around under different illuminations, the light reflected off the paper into one's eye is different, depending on whether the paper is mainly receiving bluish skylight, yellowish sunlight, or reddish lamplight. The idea is to suggest that perceiving the color red corresponds to the observer having implicit knowledge about the law that governs how the piece of paper affects the incoming light. The analogy with the sponge is now apparent: just as softness is a property of the sponge that can be tested by pressing on it, redness, it is claimed, is a property of the red paper that can be tested by moving the paper around under different light sources (or by moving oneself around the piece of paper).

Applying these ideas to the sensation of color allows for a surprisingly accurate account of color judgments, particularly the fact that certain colors – namely red, yellow, blue, and green – are in a very precise sense special: they affect incoming light in a simpler way than do all other colors. From this finding it is possible to deduce accurate predictions for well-established results from color science, in particular facts about color naming, unique hues, and hue cancellation (Philipona & O'Regan, 2006). The predictions are in fact more compatible with known empirical data than are predictions made from standard neurophysiologically based, opponent-channel models of color perception (see Figure 11.3).

6.5. *Experiments on Adaptation of Color Experience to Action*

If the quality of a sensory experience is determined by the sensorimotor interactions involved in that experience, it should be possible to change sensory quality by changing the interactions that are generally

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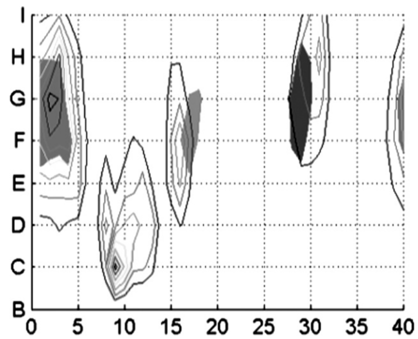

Figure 11.3. Comparison between observed and predicted salience of different surface colors. The coordinate system for a selection of Munsell color chips is the one used by Kay, Regier, and Cook (2003). For example F17 would be a particular green, G2 a particular red, C9 a particular yellow, and G28 a particular blue. The contour plots indicate the peaks where the theory proposed by Philipona and O'Regan (2006) predicts that surface colors should be singular. The patches near these peaks are taken from Berlin and Kay's (1969) world color survey (see also Kay, Regier, & Cook, 2003) and correspond to surface colors that, across a sample of 110 different languages, possessed a name for more than 20 percent of the maximum number of speakers. Thus, colors predicted to change light in a singular way are seen to correspond quite precisely with those given names across different languages.

associated with a stimulation. In an attempt to verify this prediction of the sensorimotor approach, Bompas and O'Regan (2006a, 2006b) performed a series of experiments in which a new, artificial dependency was created between a displayed color and eye movements. In one experiment, the subject wore spectacles tinted blue in one hemifield and yellow in the other. This situation has the effect that when the observer moves her eyes, say, to the left, the world is tinted with blue, and when she moves them to the right, the world is tinted with yellow. After approximately forty-five minutes of adaptation with such spectacles, the observer removes the spectacles and her perception of color is tested. It is found that when the subject looks to the left, a gray patch of color on a computer monitor now has to be tinted with yellow for it to be perceived as gray, apparently to counterbalance an excess of perceived blue on the left. When the observer looks right, the patch has to be tinted with blue for it to be perceived as gray, apparently to cancel an excess of perceived yellow on the right. This confirms that the same retinal region can give rise to two different color percepts, depending on the eyes' direction of gaze.

The result is consistent with the idea, implied by the sensorimotor approach, that experience of color depends on potential associations with actions. Further experiments have confirmed that the effect can be obtained without tinted spectacles, by systematically linking particular color changes occurring on a computer monitor to particular eye-movement directions (Bompas & O'Regan, 2006b). In all cases, the effects are not explicable by peripheral adaptation phenomena, because the very same retinal cones are being stimulated in exactly the same way, and simply depending on gaze direction the color percept is different.

6.6. *Situating Sensory Consciousness*

O'Regan et al. (2004, 2005a, 2005b) have argued that the sensorimotor approach allows one to understand what is specifically sensory about perceptual consciousness by means of the concepts of bodiliness (also corporality) and grabbiness (also alerting capacity), introduced in O'Regan and Noë (2001a,b) and in Myin and O'Regan (2002). Basically, the concepts offer an analysis of the way in which conscious perception differs from thinking or imagining.

Consider what it is to actually stand in front of an elephant compared to what it is to think about an elephant or to imagine standing in front of an elephant. In the first case, the elephant is experienced as having a sensory presence. This presence, following philosophers such as David Hume and Edmund Husserl, can be taken as a defining characteristic of sensory and perceptual experience.[6]

O'Regan et al. (2004, 2005a, 2005b) suggest that there are several important characteristics of the perceptual interactions

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involved in sensation that in a natural way provide a plausible account for this perceptual presence.

First and foremost, sensation, considered a sensorimotor interaction, is in an essential way related to body movements. Whereas the processes of thinking, deciding, and remembering can occur without potential bodily motions, the sensory processes like seeing, hearing, and touching involve potential body action in a fundamental way. This is what and O'Regan et al. (2004, 2005a, 2005b) call "bodiliness," or corporality: when one sees, the slightest movement of one's eyes, body, or the object in question necessarily immediately provokes changes in sensory input. The sensory input from the elephant changes drastically if one so much as slightly moves one's head. On the other hand, body actions do not in such a necessary fashion change the contents of our memories or our thoughts. One can keep on entertaining the same thought even while walking; and starting to walk does not automatically makes one think a different thought. When sensations are considered sensorimotor interactions it becomes possible to account for the difference between sensations and mental processes in terms of the effects bodily actions have on the former but not on the latter.

The already-introduced notion of grabbiness, or alerting capacity (O'Regan et al., 2004, 2005a, 2005b), refers to a complementary aspect of sensory systems. Grabbiness occurs because sensory systems in biological organisms are hardwired in such a way to detect sudden changes. When these occur, alerting mechanisms incontrovertibly notify the perceiver, so that his normal cognitive functioning is interrupted. When the elephant moves slightly, or when a bird flies by or a light flashes, one will automatically cast one's eye or attention on that sudden event.

This suggests that this potential alerting capacity of sensory channels is another constitutive difference that accounts in a natural way for the difference in presence between sensation and other mental processes like thoughts. Sensations impose themselves on you because they have the potential to surprise you and to divert your normal thought processes. In fact, even without the action of hardwired detectors of sudden change, sensory skills necessarily involve the organism trying to adapt to outside events that have a life of their own, escaping to some extent the control of the perceiver. Thoughts and memories on the other hand are (barring exceptional cases like obsessive thoughts) completely the product of the individual's mind, and so do not have the autonomy that characterizes sensory input. It is therefore natural that a perceiver will have quite a different feeling: less a feeling of control, more a feeling of imposition, when he or she is engaging in sensory interactions than when he or she is thinking or remembering.

Bodiliness and grabbiness are dynamic perceiver-environment relations that are typical and unique for sensation and perception, and absent in other mental phenomena such as thinking or desiring. The sensorimotor proposal, then, is that these unique features provide an account for the particular sensory or perceptual feel that differentiates awareness in sensation and perception from awareness in thoughts. So, focusing, through bodiliness and grabbiness, on the embodied and situated interaction with the environment leads – at the very least – to an interesting perspective on one of the most puzzling problems of the science of vision and perception in general, the question of consciousness and perceptual awareness. Because the sensorimotor account considers that the perceived quality of a sensation is not generated by some as-yet-unknown brain process but rather is constituted by the inherent nature of the exploratory interaction that is involved, the concepts of bodiliness and grabbiness take on an explanatory status. Now it is possible to explain, without appeal to further brain mechanisms, the differences within and between sensory modalities, and why sensations have the presence that thoughts lack. Whatever's one's opinion on whether this achieves the goal of fully bridging the explanatory gap (Levine, 1983) between perceptual consciousness and the physical world, it certainly seems to testify once more to the fruitfulness and the potential inherent in thinking of sensation and perception – in vision and other modalities – from a sensorimotor perspective.

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Notes

1 As also stressed in Findlay and Gilchrist (2003).
2 These points are also noted and discussed by Noë (2004, chap. 2).
3 Nothing in our approach precludes that the not-fully-seen elements have effects on memory or behavior. There is plenty of evidence that is often interpreted in this way (for a recent overview and discussion, see Simons and Silverman, 2004). But none of the evidence seems to us to indicate that you fully see every detail of the whole scene at any time. In other words, none of this evidence disconfirms our account.
4 Note that subjects can also do the task in an internalist way, though less efficiently (Ballard et al., 1997). The externalist mode seems to be the preferred and most optimal way to operate (this primacy of the external mode is a leading theme in Findlay and Gilchrist [2003], which provides an excellent overview of the active vision field).
5 Note that *contingency* is not the normal philosophical use of the term: what is meant are the necessary laws linking potential actions and their sensory consequences.
6 Hume (1777/1975) talks about vivacity, Husserl (1907/1973) about *Leibhaftigkeit*. On the latter notion and its potential relevance for cognitive science, see Pacherie (1999).

References

Apkarian, P. (1983). Visual training after long-term deprivation: A case report. *International Journal of Neuroscience*, *19*(1–4), 65–83.

Arno, P., Vanlierde, A., Streel, E., Wanet-Defalque, M.-C., Sanabria-Bohorquez, S., & Veraart, C. (2001). Auditory substitution of vision: Pattern recognition by the blind. *Applied Cognitive Psychology*, *15*, 509–519.

Auvray, M., Hanneton, S., Lenay, C., & O'Regan, J. K. (2005). There is something out there: Distal attribution in sensory substitution, twenty years later. *Journal of Integrative Neuroscience*, *4*(4), 505–521.

Auvray, M., Hanneton, S., & O'Regan, J. K. (2007). Learning to perceive with a visuo-auditory substitution system: Localization and object recognition with "The vOICe." *Perception*, *36*(3), 416–430.

Auvray, M., & O'Regan, J. K. (2003). L'influence des facteurs sémantiques sur la cécité aux changements progressifs dans les scènes visuelles. *Année Psychologique*, *103*, 9–32.

Bach-y-Rita, P. (1967). Sensory plasticity: Applications to a vision substitution system. *Acta Neurological Scandinavica*, *43*(4), 417–426.

Bach-y-Rita, P. (1972). *Brain mechanisms in sensory substitution*. New York: Academic Press.

Bach-y-Rita, P., Collins, C. C., Saunders, F., White, B., & Scadden, L. (1969). Visual substitution by tactile image projection. *Nature*, *221*, 963–964.

Bach-y-Rita, P., Kaczmarek, K., Tyler, M., & Garcia-Lara, J. (1998). Form perception with a 49-point electrotactile stimulus array of the tongue. *Journal of Rehabilitation Research and Development*, *35*(4), 427–430.

Bach-y-Rita, P. W., & Kercel, S. (2003). Sensory substitution and the human-machine interface. *Trends in Cognitive Sciences*, *7*(12), 541–546.

Ballard, D. H., Hayhoe, M. M., Li, F., & Whitehead, S. D. (1992). Hand-eye coordination during sequential tasks. *Philosophical Transactions of the Royal Society, Series B*, *337*, 331–339.

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*, 723–767.

Berlin, B., & Kay, P. (1969). *Basic color terms: Their universality and evolution*. Berkeley: University of California Press.

Bompas, A., & O'Regan, J. K. (2006a). Evidence for a role of action in colour perception. *Perception*, *35*(1), 65–78.

Bompas, A., & O'Regan, J. K. (2006b). More evidence for sensorimotor adaptation in color perception. *Journal of Vision*, *6*(2), 145–153.

Botvinick, M., & Cohen, J. (1998). Rubber hands "feel" touch that eyes see [Letter]. *Nature*, *391*(6669), 756.

P1: SQE
CUUS366-11 cuus366/Robbins ISBN: 978 0 521 84832 9 Top: 0.5in Gutter: 0.875in July 8, 2008 14:40

Cooke, E., & O'Regan, J.K. (2005). Manipulations of the body schema. Masters Thesis, Master de Sciences Cognitives, Ecole Normale Supérieure and Université Paris Descartes.

Cronly-Dillon, J., Persaud, K., & Blore, F. (2000). Blind subjects construct conscious mental images of visual scenes encoded in musical form. *Proceedings of the Royal Society London, Series B*, 267, 2231–2238.

Cronly-Dillon, J., Persaud, K., & Gregory, R. P. F. (1999). The perception of visual images encoded in musical form: A study in cross modality information transfer. *Proceedings of the Royal Society London, Series B*, 266, 2427–2433.

Epstein, W., Hughes, B., Schneider, S., & Bach-y-Rita, P. (1986). Is there anything out there? A study of distal attribution in response to vibrotactile stimulation. *Perception*, 15, 275–284.

Findlay, J. M., & Gilchrist, I. D. (2003). *Active vision: The psychology of looking and seeing*. Oxford: Oxford University Press.

Guarniero, G. (1974). Experience of tactile vision. *Perception*, 3, 101–104.

Hayhoe, M. (2000). Vision using routines: A functional account of vision. *Visual Cognition*, 7, 43–64.

Herslund, M. B., & Jorgensen, N. O. (2003). Looked-but-failed-to-see-errors in traffic. *Accident Analysis & Prevention*, 35(6), 885–891.

Hills, B. L. (1980). Vision, visibility, and perception in driving. *Perception*, 9(2), 183–216.

Hume, D. (1975). *Enquiries concerning human understanding and concerning the principles of morals*. Oxford: Oxford University Press. (Original work published 1777)

Husserl, E. (1907/1973) Ding und Raum. Vorlesungen 1907. [Thing and space. Lectures 1907.] In: Claesges U. (Ed.), *Hussserliana* 16. *M*. Nijhoff, The Hague.

Kay, P., Regier, T., & Cook, R. S. (2003). Focal colors are universal after all. *Proceedings of the National Academy of Sciences*, 102, 8386–8391.

Land, M. F. (2004). Eye movements in daily life. In L. M. Chalupa & J. S. Werner (Eds.), *The visual neurosciences* (Vol. 2, pp. 1357–1368). Cambridge, MA: MIT Press.

Land, M. F., & Furneaux, S. (1997). The knowledge base of the oculomotor system. *Philosophical Transactions of the Royal Society, Series B*, 352, 1231–1239.

Land, M. F., & Lee, D. N. (1994). Where we look when we steer. *Nature*, 369, 742–744.

Land, M. F., & McLeod, P. M. (2000). From eye movements to actions: How batsmen hit the ball. *Nature Neuroscience*, 3, 1340–1345.

Land, M. F., Mennie, N., & Rusted, J. (1999). The roles of vision and eye movements in the control of activities of daily living. *Perception*, 28, 1311–1328.

Langham, M., Hole, G., Edwards, J., & O'Neil, C. (2002). An analysis of "looked but failed to see" accidents involving parked police vehicles. *Ergonomics*, 45(3), 167–185.

Levine, J. (1983). Materialism and qualia: The explanatory gap. *Pacific Philosophical Quarterly*, 64, 354–361.

Mack, A., & Rock, I. (1998). *Inattentional blindness*. Cambridge, MA: MIT Press.

MacKay, D. A. (1962). Theoretical models of space perception. In C. A. Muses (Ed.), *Aspects of the theory of artificial intelligence* (pp. 83–104). New York: Plenum.

MacKay, D. M. (1967). Ways of looking at perception. In W. Wathen-Dunn (Ed.), *Models for the perception of speech and visual form* (pp. 25–43). Cambridge, MA: MIT Press.

MacKay, D. M. (1973). Visual stability and voluntary eye movements. In R. Jung (Ed.), *Handbook of sensory physiology*, (Vol. 7/3A, pp. 307–331). Berlin: Springer.

Meijer, P. B. L. (1992). An experimental system for auditory image representations. *IEEE Transactions on Biomedical Engineering*, 39(2), 112–121.

Merleau-Ponty, M. (1945). *Phénoménologie de la perception*. Paris: Gallimard.

Myin, E., & O'Regan, J. K. (2002). Perceptual consciousness, access to modality and skill theories. *Journal of Consciousness Studies*, 9(1), 47–45.

Noë, Alva (2004). *Action in perception*. Cambridge, MA: MIT Press.

O'Regan, J. K. (1990). Eye movements and reading. In E. Kowler (Ed.), *Eye movements and their role in visual and cognitive processes* (pp. 395–453). Amsterdam: Elsevier.

O'Regan, J. K. (1992). Solving the "real" mysteries of visual perception: The world as an outside memory. *Canadian Journal of Psychology*, 46, 461–488.

O'Regan, J. K., Myin, E., & Noë, A. (2004). Towards an analytic phenomenology: The concepts of "bodiliness" and "grabbiness." In A. Carsetti (Ed.), *Seeing, thinking and knowing* (pp. 103–114). Dordrecht, Netherlands: Kluwer Academic.

P1: SQE
CUUS366-11 cuus366/Robbins ISBN: 978 0 521 84832 9 Top: 0.5in Gutter: 0.875in July 8, 2008 14:40

O'Regan, J. K., Myin, E., & Noë, A. (2005a). Sensory consciousness explained (better) in terms of "corporality" and "alerting capacity." *Phenomenology and the Cognitive Sciences*, *44*(4), 369–387.

O'Regan, J. K., Myin, E., & Noë, A. (2005b). Skill, corporality and alerting capacity in an account of sensory consciousness. In S. Laureys (Ed.), *Progress in Brain Research* (Vol. 150, pp. 55–68). Amsterdam: Elsevier.

O'Regan, J. K., & Noë, A. (2001a). A sensorimotor account of vision and visual consciousness. *Behavioral and Brain Sciences*, *24*(5), 883–917.

O'Regan, J. K., & Noë, A. (2001b). Acting out our sensory experience. *Behavioral and Brain Sciences*, *24*(5), 955–975.

O'Regan, J. K., Rensink, R. A., & Clark, J. J. (1999). Change blindness as a result of "mudsplashes." *Nature*, *398*, 34.

Pacherie, E. (1999), Leibhaftigkeit and representational theories of perception. In J. Petitot, F. Varela, B. Pachoud, & J.-M. Roy, (Eds.), (*Naturalizing phenomenology: Issues in contemporary phenomenology and cognitive science* (pp. 148–160). Stanford, CA: Stanford University Press.

Philipona, D., & O'Regan, J. K. (2006). Color naming, unique hues and hue cancellation predicted from singularities in reflection properties. *Visual Neuroscience*, *23*(3–4), 331–339.

Philipona, D., O'Regan, J. K., & Nadal, J.-P. (2003). Is there something out there? Inferring space from sensorimotor dependencies. *Neural Computation*, *15*(9), 2029–2050.

Philipona, D., O'Regan, J. K., Nadal, J.-P., & Coenen, O. J.-M. D. (2004). Perception of the structure of the physical world using unknown multimodal sensors and effectors. *Advances in Neural Information Processing Systems*, *15*.

Poincaré, H. (1905). *La valeur de la science*. Paris: Flammarion.

Ramachandran, V. S., & Rogers-Ramachandran, D. (2000). Phantom limbs and neural plasticity. *Archives of Neurology*, *57*(3), 317–320.

Rayner, K. (1998). Eye movements in reading and information processing: 20 years of research. *Psychological Bulletin*, *124*(3), 372–422.

Rayner, K., Sereno, S. C., & Raney, G. E. (1996). Eye movement control in reading: A comparison of two types of models. *Journal of Experimental Psychology: Human Perception and Performance*, *22*(5), 1188–1200.

Reichle, E. D., Rayner, K., & Pollatsek, A. (2003). The E-Z reader model of eye movement control in reading: Comparisons to other models. *Behavioral and Brain Sciences*, *26*, 445–526.

Reilly, R., & Radach, R. (2003). Foundations of an interactive activation model of eye movement control in reading. In J. Hyönä, R. Radach, & H. Deubel (Eds.), *The mind's eye: Cognitive and applied aspects of eye movements* (pp. 429–455). Amsterdam: Elsevier.

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*, 368–373.

Rensink, R. A., O'Regan, J. K., & Clark, J. J. (2000). On the failure to detect changes in scenes across brief interruptions. *Visual Cognition*, *7*, 127–146.

Sampaio, E., Maris, S., & Bach-y-Rita, P. (2001). Brain plasticity: "Visual" acuity of blind persons via the tongue. *Brain Research*, *908*, 204–207.

Simons, D. (2000). Current approaches to change blindness. *Visual Cognition*, *7*, 1–16.

Simons, D. J., & Chabris, C. F. (1999). Gorillas in our midst: Sustained inattentional blindness for dynamic events. *Perception*, *28*(9), 1059–1094.

Simons, D. J., Franconeri, S. L., & Reimer, R. L. (2000). Change blindness in the absence of visual disruption. *Perception*, *29*, 1143–1154

Simons, D. J., & Levin, D. T. (1997). Change blindness. *Trends in Cognitive Sciences*, *1*, 261–267.

Simons, D. J., & Rensink, R.A. (2005). Change blindness: Past, present, and future. *Trends in Cognitive Sciences*, *9*, 16–20.

Simons, D. J., & Silverman, M. (2004). Neural and behavioral measures of change detection. In L. M. Chalupa & J. S. Werner (Eds.), *The visual neurosciences* (Vol. 2, pp. 1524–1537). Cambridge, MA: MIT Press.

Tastevin, J. (1937). En partant de l'expérience d'Aristotle. *L'Encephale*, *1*, 157–184.

Thomas, N. (1999). Are theories of imagery theories of imagination? An active perception approach to conscious mental content. *Cognitive Science*, *23*, 207–245.

Tsakiris, M., & Haggard, P. (2005). The rubber hand illusion revisited: Visuotactile integration and self-attribution. *Journal of Experimental Psychology: Human Perception and Performance*, *31*, 80–91.

Tyler, M., Danilov, Y., & Bach-y-Rita, P. (2003). Closing an open-loop control system: Vestibular substitution through the tongue.

P1: SQE
CUUS366-11 cuus366/Robbins ISBN: 978 0 521 84832 9 Top: 0.5in Gutter: 0.875in July 8, 2008 14:40

Journal of Integrative Neuroscience, 2(2), 159–164.

Vitu, F. (1999). About saccade generation in reading. *Behavioral and Brain Sciences*, 22, 702–703.

Vitu, F. (2003). The basic assumptions of E-Z reader are not well-founded. *Behavioral and Brain Sciences*, 26(4), 506–507.

Yang, S.-N., & McConkie, G. W. (2001). Eye movements during reading: A theory of saccade initiation times. *Vision Research*, 41, 3567–3585.

Yang, S.-N., & McConkie, G. W. (2004). Saccade generation during reading: Are words necessary? *European Journal of Cognitive Psychology*, 16(1–2), 226–261.