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Beyond the Grand Illusion: What Change Blindness Really Teaches Us About Vision

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Experiments on scene perception and change blindness suggest that the visual system does not construct detailed internal models of a scene. These experiments therefore call into doubt the traditional view that vision is a process in which detailed representations of the environment must be constructed. The non-existence of such detailed representations, however, does not entail that we do not perceive the detailed environment. The "grand illusion hypothesis" that our visual world is an illusion rests on (1) a problematic "reconstructionist" conception of vision, and (2) a misconception about the character of perceptual experience.

INTRODUCTION

A recent body of psychological experiments demonstrates that normal adult humans are very bad at noticing changes to visible features of the environment. These experiments on "change blindness" fall into three main categories (for a more detailed review, see Intraub, 1997; Simons, this issue; Simons & Levin, 1997).

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(1) An initial group of studies demonstrates convincingly that the ability of perceivers to detect changes in photographs of natural scenes is greatly impaired when the changes occur during saccades (Currie, McConkie, Carlson-Radvansky, & Irwin, 1995; Grimes, 1996; McConkie & Currie, 1996). These investigations grew out of earlier work on the integration of visual information across saccadic eye movement (Bridgeman, Hendry, & Stark, 1975; McConkie & Zola, 1979).

(2) A second group of experiments demonstrates that the inability to detect such changes does not result from specifically saccade-dependent mechanisms of suppression (Blackmore, Brelstaff, Nelson, & Troscianko, 1995; O'Regan, Rensink, & Clark, 1996; Rensink, O'Regan, & Clark, 1997). In one study, an image of a natural scene is continually alternated with a modified image, with a blank mask inserted between each display. Subjects find changes very difficult to notice under these "flicker conditions", even though the changes are large and would be easily observable under different conditions (Rensink et al., 1997). Another study demonstrates that if transients unrelated to the changes ("mud splashes") occur at the same time as the changes, the ability of subjects to detect the changes is greatly reduced, even though the mud splashes do not obscure the changes themselves (O'Regan et al., 1996). Change detection is similarly impaired for changes correlated with eye blinks (O'Regan, Deubel, Clark, & Rensink, this issue; O'Regan, Rensink, & Clark, 1997). These investigations demonstrate that change detection can be prevented by disrupting the visual system's ability to respond to the motion transients produced by the changes. The explanation for this finding, according to Rensink et al., (1997), is that motion transients are low-level cues for the direction of attention. What the studies show, therefore, is that "the visual perception of change in a scene occurs only when focused attention is given to the part being changed" (p. 368).

(3) A third group of studies suggests that change blindness is not related to the passive viewing conditions typically employed in the laboratory setting. In one study subjects attempt to copy a pattern of coloured blocks from a "resource" to a "workspace" area based on a fixed set of blocks in the "model" area (Hayhoe, Bensinger, & Ballard, 1998). As they saccade, either one or several blocks in the model area are altered. Even though the changes occur at "regions of interest", subjects tend to notice them only rarely. In a surprising and fascinating recent study, Simons and Levin (1998, see also 1997) show very low rates of change detection when the changed item is a real person with whom the subject is actively conversing. Although more controlled studies are needed, this study indicates that change blindness is not a laboratory artifact, but also occurs in real-world situated perception.

Taken together, the change blindness literature suggests the following hypothesis: Subjects notice only changes to features that have been encoded by the visual system. Thus, change blindness suggests that under normal viewing conditions only a minor part of the environment is encoded in detail. Although the factors that determine which features of a scene are encoded remain unknown, it seems likely that attention plays a major role (Rensink et al., 1997).

In a review article, Simons and Levin (1997, p. 267) state: "Given the failures of change detection we must question the assumption that we have a detailed representation of our visual world." We explore the significance of this hypothesis here. We argue, first, that the hypothesis is best appreciated against the background of the widely held view that vision is a process whereby the brain constructs an elaborate representation of the visible world on the basis of information encoded on the retina (see, e.g. Marr, 1982; Poggio, Torre, & Koch, 1985). The change blindness studies provide evidence against this sort of "reconstructionist" conception of vision.[1] Second, we argue that the evidence in favour of the hypothesis that the visual system lacks detailed representations of the visual world provides no support for the much stronger thesis that "the visual world is an illusion". Not only visual scientists but philosophers have proposed that the change blindness studies support this "grand illusion hypothesis" (Blackmore et al. 1995; Dennett, 1991, 1992, 1998; O'Regan 1992; Rensink et al. 1997). We argue that this position rests either on the problematic reconstructionist conception of vision (which the change blindness studies themselves call into question), or on misunderstandings about the character of perceptual experience. Widespread adherence to the view that seeing is a process whereby the brain builds up detailed internal models has obscured the fact that vision is a capacity of the whole situated animal. We show later that the change blindness studies lose their puzzling character once one emphasizes that seeing is the temporally extended activity of visually exploring the environment.

CHANGE BLINDNESS AND THE REAL MYSTERIES OF VISUAL PERCEPTION

Theorists have long been impressed by the fact that visual experience is underdetermined by the input to the visual system. The eye is in nearly constant motion; the resolving power (spatial and chromatic) of the retina is limited and non-uniform; passage to the retina is blocked by blood vessels and nerve fibres; there is a large "blind spot" on the retina where there are no photosensitive receptors; there are two retinal images, each of which is inverted. As Gregory (1966/1978, p. 9) has written: "We are given tiny distorted upside-down images in the eyes and we see separate solid objects in surrounding space. From

[1]The account of the nature of vision we criticize has been called "the literalist view" by Akins (1996) and Ballard (1996).

the patterns of stimulation on the retinas we perceive the world of objects, and this is nothing short of a miracle". *The* central puzzle for traditional visual science—what O'Regan (1992) has called "the real mysteries of visual perception"—is to account for this apparent miracle, to explain how the brain bridges the gap between what is given to the visual system and what is actually experienced by the perceiver.

These starting assumptions influence not only what some visual scientists think vision is (the process whereby the brain constructs an accurate and detailed internal model of the environment on the basis of a defective and impoverished retinal image), but also the way these theorists approach particular problems. Consider two examples.

Example 1: The problem of perceptual stability despite the observer's eye movements. When you visually track a moving object against a stable background, the projected retinal image of the moving object tends not to move relative to the retinal projection as a whole, while the retinal projection of the background, which is perceived as still, races across the retina (Bridgeman, van der Heijden, & Velichkovsky, 1994). How can we explain this puzzling fact? In general, we might ask: How does the visual system succeed in representing the perceptual world as stable despite the constant movement of the projections of that environment relative to the retina as a whole? One proposal, put forward by Sperry (1950) and Von Holst and Mittelstaedt (1950, 1971), is that the visual system uses information about the movement of the eye to "compensate for" the effects of eye movement. Such compensation enables the visual system to construct a neural correlate of the perceptual experience of a stable world. Other proposals have been put forward (for a review, see Bridgeman et al., 1994). Each such proposal seeks to explain mechanisms by means of which the visual system can construct the appropriate internal model of the world despite the defective character of the input.

Example 2: The blind spot. We have a blind spot in each eye corresponding to the region where the optic nerve leaves the retina and there are no photoreceptors. In everyday perception we are never aware of the blind spot. The blind spots of the two eyes do not overlap, and something that falls on the blind spot of one retina will fall outside the blind spot of the other retina. Even under monocular viewing the blind spot is not easily revealed. This is an example of perceptual completion or visual filling-in: The colour and brightness surrounding the area corresponding to the blind spot are said to "fill in" that area so that a uniform expanse is perceived. The existence of such perceptual completion phenomena is uncontroversial. Many theorists, however, take for granted that this perceptual phenomenon is accomplished by the brain's providing something to make up for an absence—by the brain's actively filling in the missing information. It is commonly supposed that some such process of neural filling-in must occur to account for the discrepancy between how things visually seem to us and the actual character of the proximal stimulus. (For a review of empirical and conceptual controversies surrounding perceptual completion, see Pessoa, Thompson, & Noë, 1998.)

Notice that the treatment of these problems exhibits a common pattern of reasoning. There *must* be active processes of compensation for retinal displacement or neural filling-in in order to account for the discrepancy between how things are experienced and what is encoded in early vision. The task of visual science is to discover the function mapping the initial retinal encoding of visual information onto the eventual neural substrate of perceptual experience (what Teller & Pugh, 1983 have called "the bridge locus").

Is it true that there *must* be such active processes of neural compensation, and must they take the form of reconstruction? Recently, theorists have begun to challenge this traditional pattern of reasoning. Consider the two examples again.

Example 1. Many proposals to explain visual stability share the following assumption (Bridgeman et al., 1994): A saccadic eye movement produces a change in the location within the brain of the brain's representation of an object. This assumption prompts theorists to propose special mechanisms of compensation to eliminate such changes in position to guarantee stability. Bridgeman et al. question this assumption. The representation of an object's position in the world should not be confused with the position (within the brain) of that representation. The position in a topographically organized brain map need not be the code for object position in the environment. Analogously, movement in the world need not be represented by "movement" in such maps. As Bridgeman and colleagues (1994, p. 225) put the point: "The idea that there is a movement perception problem when the eyes saccade arises from thinking about what happens during a saccade, and from confusing the position of representing an object in the brain with the position of the object that is represented in the world." Once this problematic pattern of reasoning is noticed, however, we can appreciate that there is no better reason to suppose that retinotopic movement represents real movement than there would be to suppose that the orientation of the retinal image encodes the orientation of objects in the environment, or that the number of retinal images (two) encodes the number of objects perceived. The upshot of this line of thought is that it was a mistake to believe that there *had to be* an active mechanism to compensate for retinal displacement. Once this is realized, others kinds of account can be sought after.

Example 2. A similar point holds in the case of the blind spot. From the fact that one has no awareness of a gap in one's visual field, it does not follow that there must be a neural representation of a gapless visual field (of the gaplessness of the visual field), for there is more than one way (at least in principle) in which the brain can produce such a percept. One alternative to the neural filling-in hypothesis is that the brain might simply ignore the absence of receptor signals at the blind spot. If a bar falling across the blind spot is not represented as having a gap in need of filling in, then there would be no need for a filling-in process (Dennett, 1991, 1992; O'Regan, 1992; Pessoa et al., 1998; see Ratliff & Sirovich, 1978 for related ideas). In the absence of direct empirical evidence for neural filling-in, there is no good reason to *assume* that the brain fills in the blind spot in the sense of actually propagating nervous activity to make up for an absence, or in the sense of providing a roughly continuous spatial representation (i.e. a picture). (As a matter of fact, there is strong empirical evidence in support of active neural completion in certain cases. See Pessoa et al., 1998 for a discussion of this topic.)

The significance of the change blindness studies first emerges in the context of these methodological considerations. First, change blindness provides evidence against the existence of detailed internal models. Second, it provides evidence against the analysis according to which vision just is the process of constructing such models.

These points can be appreciated by considering briefly the problem of the integration of visual information across saccadic eye movement. When we reflect on our perceptual experience of the environment, we take ourselves to be smoothly scanning the scene (Grimes, 1996). We watch the events and happenings through the unobstructed windows of our eyes. In fact, however, our eyes are like shutters. Not only do we blink once or twice a second, but saccadic suppression occurs three or four times a second. We are not aware that the eye acquires visual information only during these brief and interrupted windows between eye movements. Once again the visual system presents us with an enormous gulf between the character of its early informational content and the content of conscious perceptual experience. Here as elsewhere theorists and experimentalists assume that there must be processes by means of which the brain constructs a representation whose character and content match that of the conscious experience. The visual system integrates information from the temporally extended sequence of fixations into an internal model of the environment.

The change blindness studies are directly relevant to how we assess hypotheses about the integration of visual information across saccades. They suggest that it is mistaken to suppose that the visual system has to build up such integrated world-models, and therefore that it is mistaken to suppose that vision in general requires such models.

We would like to emphasize that we do *not* argue that it is a mistake to posit mechanisms of reconstruction to account for perception. What we argue is that it is a mistake to assume that there *must* be such mechanisms, even in the absence of direct evidence of their existence. In addition, in our view, it is a mistake to suppose that the visual system *must* compensate for each and every "defect" of early visual encoding. Whether there is such compensation in any given case, and whether, given need for compensation, it takes the form of active reconstruction, are (or ought to be) open empirical questions.

Caveat

It is important to recognize that although the change blindness results count against there being robust internal representations of the environment, they do not place this conclusion beyond doubt. Failure to detect changes provides evidence of the absence of richly detailed internal representations in so far as one can explain the inability of subjects to make such detections by supposing them to lack the relevant detailed representations. Other explanations of the inability to notice changes may become available, however. Perhaps the visual system does produce the disputed representations, but fails to make them available to memory or to verbal report. Rensink and colleagues (1997) assume that attention functions as a bottleneck on what is encoded, but perhaps memory or other "access limitations" provide a bottleneck on what information can be used in making reports about the detection of changes. This possibility deserves to be investigated further, especially in light of Hayhoe et al.'s (1998) finding that change blindness is sometimes accompanied by non-verbal behavioural correlates of awareness (see also Fernandez-Duque & Thornton, this issue).

BEYOND THE HYPOTHESIS OF THE GRAND ILLUSION

Do the change blindness results show that the visual world is an illusion? Some theorists seem to think so. O'Regan and his colleagues (1996, p. 213) suggest that the "impression of continuously seeing 'all' of a visual scene may be an illusion deriving from the fact that any change usually creates a visual transient that attracts attention to the changing location". Blackmore and her colleagues (1995, p. 1075) write: "we believe that we see a complete, dynamic picture of a stable, uniformly detailed, and colourful world," but "Our stable visual world may be constructed out of a brief retinal image and a very sketchy, higher-level representation along with a pop-out mechanism to redirect attention. The richness of our visual world is, to this extent, an illusion." These remarks are somewhat unclear. Exactly what kind of illusion do O'Regan et al. and Blackmore et al. have in mind?

The reconstructionist argument

Adherence to a reconstructionist conception of vision might lead one to think that the change blindness results show that the visual world is an illusion in the following sense: If vision just is the neural process whereby detailed internal models of the scene are constructed from retinal information, then evidence that the visual system does not construct such detailed models is *ipso facto* evidence that we do not see the detail we think we do.

This argument is unsatisfactory. As we noted in connection with filling-in and visual stability, it is a mistake to *assume* that the brain encodes what is seen by means of detailed internal models. It follows that the evidence against the existence of such models is not, in itself, evidence that we do not see what we seem to see.

The hypothesis that there are no highly detailed internal models of the environment in the brain does not entail the grand illusion hypothesis. We agree with O'Regan (1992, p. 484) when he writes: "seeing constitutes an active process of probing the external environment as though it were a continuously available *external memory*" [his italics]. Because the world is present for our perusal and investigation, there is no need for the visual system to construct an internal model. To suppose that the grand illusion hypothesis follows from the mere absence of a detailed internal model amounts to reinstating the problematic reconstructionist conception of vision, according to which seeing just is the construction of such a model in the brain. But it is important not to confuse *what it is* for an animal to see with *how* the visual system gives rise to vision. For an animal to see is for it to have a visual perceptual system that enables it to guide its action and explore its environment (Gibson, 1979; Nakayama, 1994). Whether vision in this sense arises from detailed internal models in the visual system is precisely the question raised by the change blindness studies that must not be prejudged.

This conclusion is clearly one that O'Regan et al., Blackmore et al., and most researchers on scene perception would accept. What, then, is the illusion to which they call attention?

Perceptual experience and the grand illusion

Consider a second argument for the grand illusion hypothesis. This argument is of a more philosophical nature. Experience requires a neural basis. We could not have perceptual experiences which represent the environment in high-resolution detail if we lacked the neural representations necessary to produce them. The change blindness studies (at least on a plausible interpretation) demonstrate that we lack the required detailed brain representations and that, consequently, we have a false idea of the character of our own experiences. We (everyday people, that is) are the victims of an illusion—not a perceptual illusion about the world, but rather an illusion about the nature of our visual experience. We are misled as to the actual character of experience. Philosophers have long held that although we may never be certain about how things really are in the world, we can at least be certain about how things look to us. The change blindness studies, according to the line of reasoning we are now considering, show that we are (sometimes) mistaken even about the character of our own conscious visual experience: It seems to us that we are visually aware of the world in all its detail, but the change blindness studies allow “the illusory nature of our subjective impressions to become apparent” (Rensink et al., 1997).

There is evidence that visual scientists, as well as philosophers, subscribe to this argument. O’Regan (1992, p 484), for example, writes: “despite the poor quality of the visual apparatus, we have the subjective impression of great richness and ‘presence’ of the visual world: But this richness and presence are actually an illusion, created by the fact that if we so much as faintly ask ourselves some question about the environment, an answer is immediately provided by the sensory information on the retina, possibly rendered available by an eye movement.” Notice that the illusion here cannot be a perceptual one; O’Regan is not claiming that vision misleads us about the richness and detail of the actual world. The illusion pertains, rather, to our “subjective impression of … the visual world”. We are misguided as to the real character of our subjective impressions. A similar idea is expressed by Simons and Levin (1997). They write (p. 267): “Thus, change blindness supports the phenomenal experience of continuity by not preserving too much information from one view to the next.” We have the experience of continuity because, in fact, our actual perceptual contact with the environment is fragmented and discontinuous. Blackmore’s claim that to some extent the visual world is illusory should perhaps be interpreted this way as well. The visual world, as distinct from the actual world, is a figment of our constructive visual processing. We don’t really experience things as we think we do.

The sharpest development of these ideas is to be found in the work of Dennett. He writes (1992, p. 48), “One of the most striking features of consciousness is its *dis*continuity. Another is its *apparent* continuity.” Ordinary people simply have a false conception of what their experience is like. According to Dennett, lay people tacitly endorse the idea that to experience detail, the detail must be in the head (1998; see also Rensink, this issue). And so they are further committed to the idea that the explanation for the apparent continuity of consciousness is that the brain fills in the gaps, by, for example, filling in at the blind spot and integrating information across saccades in the form of detailed world-models (Dennett, 1998; see also 1992). Dennett writes (1998, p. 754): “It is, if you like, a theorist’s illusion, but it turns out that we are all theorists. That is we tend to assume … that there is more in the brain than there has to be.” Indeed, it is precisely this fact, Dennett argues, that explains why everyday people, and not only theorists of vision, are so surprised when they experience the change blindness effects (unpublished comments on a previous version of this paper).

In our view, this argument falters because (1) its account of what change blindness tells us about perceptual experience is mistaken; and (2) it misdescribes the character of perceptual experience. We review these points in turn.

First, do the change blindness experiments show that we lack the brain-level representations required to produce perceptual awareness of a richly detailed environment? Clearly not. We have already examined this issue earlier in this section. The change blindness studies show that we lack certain kinds of internal representations. They do not show that such representations are required for vision. Nor does the absence of detailed internal world-models imply that experience is discontinuous. If we reject the assumption that to see the detail in the environment is to represent that detail in the head by means of an elaborate model, then we must rethink the significance of the supposedly "defective" character of the visual apparatus. For example, the limitations of parafoveal vision give us reason to believe that a person *could not* learn all the detail in a scene on the basis of a single fixation. But seeing a scene is not a matter of isolated fixations. We look first here, then there (all the while saccading to be sure), and thus come to learn and (at least some of the time) take note of the environment's details and features. One way to put this point is that *what we see* is not the value of a function over isolated fixations; it is, rather, the result of a temporally extended process of *looking*. The limitations on parafoveal vision (and other such "defects" of the input devices) are in a very important sense *not* limitations on the act of looking and the process of learning. They are merely some of its neural enabling conditions. Although the information encoded on the retina does not specify the environment in all its detail, and although the brain may not construct a detailed model of the scene, the environment is detailed, and the mobile and exploring animal is able to discover that detail by active exploration.[2]

Second, how do we visually experience the environment? It is misleading to say that "we believe that we see a complete, dynamic picture of a stable, uniformly detailed, and colourful world" (Blackmore et al., 1995, p. 1075). The main sense in which we take our visual experience to be uniform and continuous is that we take ourselves to be perceptually aware of a spatio-temporally continuous environment. And in this belief we are right. Furthermore, to say that we (ordinary perceivers) normally think we perceive all environmental detail with equal focus and clarity—as if we were looking at a fixed picture—is to misdescribe the character of perceptual experience. Consider, as an example, the experience of looking out the window. If you fix your gaze and reflect on

[2]In place of the problematic "reconstructionist" analysis, we advocate the "enactive" theory of vision (Noë, in press; Pessoa et al., 1998; Thompson, Palacios, & Varela, 1992; Varela, Thompson, & Rosch, 1991). The enactive approach to vision is influenced by the "ecological" approach of Gibson and his followers (Gibson 1979; Turvey, Shaw, Reed, & Mace, 1981; Turvey, Solomon, & Burton, 1989), by recent work on "animate" vision (Ballard, 1991, 1996; Ballard, Hayhoe, Pook, & Rao, 1997), and by the general trend in cognitive science towards an embodied, situated perspective on perception and cognition (Chiel & Beer, 1997; Clark, 1997). On the enactive view, the proper subject of vision is not the visual system, but rather the whole, active, situated animal.

what you see, you will find that although you see a detailed and variegated scene, you do not, as it were, see all the detail with equal clarity. At the periphery of the visual field, for example, things are harder to make out. This can be explained by the properties of foveal and parafoveal vision. Our present concern, however, is not with such explanations, but rather with the simple fact that when you fix your gaze and look out, it does not seem to you as if you simultaneously see all the detail with equal clarity. Notice, however, that although you do not see the detail with uniform clarity, you do see that the world is uniformly detailed (that is, you correctly judge the world to be detailed on the basis of what you see). To suppose that we take ourselves to experience all the detail, with uniform clarity, as it were simultaneously, is to misdescribe the phenomenology of vision.[3]

Ordinary perceivers are surprised and nonplussed by the change blindness effects. Levin, Momen, Drivdahl, and Simons (this issue) have provided evidence that naïve observers consistently believe that they would detect changes in the environment. To explain this fact, must we suppose that everyday perceivers are committed to a strong conception of the brain bases of visual perception, that they believe they store the detail in the head (as suggested by Dennett, 1992, 1998; Rensink, this issue)? In other words, when we look at a detailed scene, does it seem to us as if all that detail is represented in our brains? No. It seems to us as if all the detail is in the environment, which is where, in fact, it is. A crucial feature of ordinary perceptual experience is what we can call its transparency: Perception aims directly at the world and does not ordinarily involve beliefs about what goes on in the brain when we perceive (Dennett's claims to the contrary notwithstanding). The beliefs we are likely to form on the basis of our perceptual experiences are beliefs not about neural representations, but about what we perceive. We are not all theorists when it comes to seeing. To suppose that perceptual experience involves beliefs about the brain is falsely to intellectualize perception (Pessoa et al., 1998).

Why do we (ordinary perceivers) find the change blindness results so surprising? For the same reason we are impressed and astounded by the skilful magician. We feel that we ought to be able to notice what takes place before our eyes. The change blindness studies demonstrate convincingly that we are not as good at noticing changes that take place smack dab in front of us as we would like to think. There is no need for a more esoteric explanation than this. Artists, set designers, and magicians, it is interesting to consider, have for centuries traded on precisely these familiar perceptual limitations. It is when combined with questionable methodological doctrines that the change blindness results

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[3]Mach ran up against these difficulties when he attempted to produce a drawing of his visual field (Mach, 1906/1959, p. 19). The drawing fades to white at the edges, as if that was an adequate representation of the relative indistinctness of the periphery of the visual field! For more on this see Thompson, Noë, and Pessoa (in press).

seem to give rise to paradox. Once theorists make peace with the idea that it is not necessary to represent all the detail internally to see the elaborate detail of the world, the change blindness results assume more modest dimensions: Vision enables us to learn about a wide range of features of the environment, but there is a good deal that goes on around us that we fail to notice.

CONCLUSION: TO SEE THE DETAIL IN THE WORLD IS NOT TO HAVE THE DETAIL IN THE HEAD

Recent theoretical investigations of such topics as filling-in (Dennett, 1991; O'Regan, 1992; Pessoa et al., 1998), visual stability despite eye movement (Bridgeman et al., 1994), and now change blindness, suggest that the neural bases of vision may not require elaborate world-model construction. These investigations support our contention that visual science should reject the traditional reconstructionist conception of vision. It is of course one thing to reject a traditional way of thinking about vision, and another to come up with a serviceable replacement. On the enactive approach we favour (Noë, in press; Pessoa et al., 1998; Thompson et al., 1992), seeing is an activity of the whole animal—visually guided exploration of the environment—not the construction of a world-model in the brain. Of course, internal world-models could turn out to be needed for vision to perform its action-guiding role. This matter is an open empirical one, however, not something that can be decided on the basis of theoretical reflection.

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