Kicking the Kohler Habit

Colin Klein
University of Illinois at Chicago

1 Introduction: Weak and Strong Enactivism

Like many philosophers, I first learned of Kohler's experiments with goggles in a psychology class. Like many philosophers, I was intrigued by the apparently striking results. According to the standard story—I'll call it **KH**—Kohler showed that vision eventually re-inverted after suitable experience wearing such goggles. Further, the story goes, that re-inversion coincided with a return of skillful behavior in the world. This striking empirical phenomenon in turn gave plausibility to philosophical theories of perception that emphasized the role of skilled action in perception. The most notable among such recent theories has been *enactivism*, which argues that perceptual content supervenes on precisely the sort of sensorimotor knowledge that Kohler showed was crucial to visual re-inversion.

Unfortunately, **KH** is wrong. Subsequent experiments have shown that visual re-inversion is a complicated phenomenon at best, and does not coincide with the return of sensorimotor knowledge. Perhaps most strikingly, Kohler himself doesn't appear to believe in **KH**, and support for it is difficult to find in his work. The habit of relying on Kohler's supposed results to make philosophical claims thus turns out to be a philosophical liability rather than an asset.

The goal of the present paper is modest. I will argue that the evidence is against **KH**, and that experiments specifically designed to test **KH** provide good evidence that it is false. That is bad for strong forms of enactivism. Enactivism is committed to **KH** being roughly true; evidence that it is false thus speaks against strong enactivism.

2 The Kohler Habit

Enactivism has been notable for its appeal to behaviorally-based facts to anchor perceptual ability. Kevin O'Regan and Alva Noë have coined the term "sensorimotor contingencies" for the facts about how stimulation changes as a function of a perceiver's movement and/or

movement or other change in a perceived object or in other environmental conditions (O'Regan & Noë, 2001). The enactivist thesis claims that perceptual capacities are determined by knowledge of sensorimotor contingencies. Broadly speaking, perceptual content is determined by a perceiver's understanding of the ways in which the stimulation she is receiving would change as a result of her movement or of some change her environment. Sensorimotor contingencies are the sort of thing that can be controlled and manipulated; as such, enactivism opens itself to—and indeed has embraced—empirical testing.

In treating this recent trend in the theory of perception in this paper, I will focus on Noë's "enactive approach", as developed in his recent monograph Noë, 2004, because I take Noë's approach to be a particularly clear and compelling example approaches to perception along these lines.[1] Broadly speaking, Noë's answer to the question of what determines the contents and character of perceptions is this: "*What we perceive* is determined by *what we do* (or what we know how to do); it is determined by what we are *ready* to do" (Noë, 2004 p1).

Note that this claim can be read in two ways. Enactivism could be the thesis that that what we perceive is *partly* determined by what we are ready to do—that is, that there are determining influences on the contents and character of perceptions coming from sensorimotor knowledge. Or, Noë could claim that what we perceive is *entirely* determined by what we are ready to do. Call these two possible positions *weak* and *strong* enactivism, respectively. In the present work, I will focus on strong enactivism.

Strong enactivism entails that it would be impossible for two subjects who were alike in their respective grasps of the relevant sensorimotor contingencies to differ in the contents and/or character of their visual perceptions when presented with the same visual display. According to strong enactivism, any two subjects who are ready to do the same things should *see* the same thing. The same is true if the 'two' subjects in question are one

subject at different times.

This claim can be tested. Suppose that we gave subjects inverting goggles—i.e., goggles with lenses that redirect incoming light so that the array is rotated around the horizontal axis. Strong enactivism predicts that if a subject wore inverting goggles for long enough to master the new sensorimotor contingencies, then there should be no difference between the content and character of the subject's perceptions before she donned the goggles and the content and character of her perceptions after growing accustomed to the goggles. Crudely put, what she sees should 'right itself'. If the subject's visual image does not right itself exactly when sensorimotor knowledge is restored, then some other factor must be required to determine the contents and character of human visual perceptions.

The use of inverting goggles provides a useful test of enactivism, in part because *failure* should be obvious and strongly disconfirmatory. JG Taylor, perhaps the first proponent of using goggles to establish something like enactivism, puts the logic of the test well:

> We return now to the question that was raised [before], whether any failure of the observed results to confirm the deduction would constitute a fatal objection to the theory. It is important here to understand clearly what is meant by failure. It means not just that the predicted perceptual result does not occur, but that it fails to occur despite the fact that the postulated behavioral transformation has been completed....
>
> If any of the predicted perceptual results had occurred while the relevant behavior was still disrupted, that would also constitute a failure, and it is obvious that this kind of failure would have fatal consequences for the theory, since it would imply that some mechanism other than behavioral adaptation was responsible for the result. It should be noted, however, that the mere occurrence of behavioral and perceptual change does not constitute a real test of the theory. If we assume, as many psychologists have done, that the function

> of perception is to control behavior, then any change in perception would automatically bring about a change in behavior, so that the concurrence of behavioral and perceptual changes is consistent with both theories...
> (Taylor, 1963 pp220–1)

In other words, inversion goggles might provide evidence against enactivism in two ways. If visual re-inversion fails to occur when the new sensorimotor contingencies are mastered, or if it occurs *without* regaining mastery of the new sensorimotor contingencies, then enactivism is false. Only if visual re-inversion occurs precisely when the new sensorimotor contingencies are mastered will enactivism gain empirical support. Inverting goggles thus provide a strong test of enactivism. Visual re-inversion at the proper time would provide slight (but solid) evidence for enactivism. A failure of re-inversion at the proper time would provide strong evidence against enactivism.

There is a widely held misconception that **KH** is true, and so enactivism passes this test. It is thought that this was established by experiments with inverting goggles performed by G.M. Stratton and elaborated upon by Ivo Kohler (Stratton, 1897; Kohler, 1961, 1964. Noë clearly believes in the truth of **KH**. For instance, he says, "Perceptual adaptation to inverting goggles is, therefore, in the first instance, a process whereby sensorimotor understanding, and with it perceptual content, is restored" (Noë, 2004 p. 91). A bit later, he claims that "Perceptual adaptation, from the enactive standpoint, is a process of learning to apply the appropriate sensorimotor knowledge. Once this is accomplished, content is refashioned. Veridicality is restored" (Noë, 2004, p. 92).

Moreover, Noë clearly believes that the truth of **KH** supports his enactive approach. For instance, he says, "The enactive view would also lead us to expect that vision will be restored once one comes to grips with the new patterns of sensorimotor dependence. The experimental literature supports this" (Noë, 2004, p. 9). And he says, "From the standpoint of the enactive view, this is an extraordinarily important phenomenon, a

powerful illustration of the fact that perceptual experience acquires content as a result of sensorimotor knowledge" (Noë, 2004, p. 9).

From the standpoint of *strong* enactivism, this supposed phenomenon is more than extraordinarily important. It is absolutely crucial. If upright vision is not restored once one comes to grips with the new patterns of sensorimotor dependence—i.e., if **KH** is false—then strong enactivism is false.

3 Kicking the Habit

KH is false. For starters, it is not clear that Kohler himself argued for **KH**. Kohler is largely concerned with showing that the visual adaptation that *does* occur occurs centrally rather than peripherally (*pace* Hering's theory of after-effects) (Kohler, 1961, ch. 4.). As such—and this is frustrating to his would-be interpreters—Kohler often describes the visual effects only in broad strokes, and just precisely enough to allow comparison with after-effects. Further, Kohler most frequently mentions re-inversion only of particular *objects*, rather than the whole visual field (Kohler, 1961, pp. 32ff.). This casts doubt on whether Kohler is describing true re-inversion rather than some other, more difficult to interpret, process.

Moreover, experiments by Hirokazu Yoshimuro and Charles Harris cast significant doubt on **KH** . Both have shown evidence for a change in body-image, but the evidence for visual re-inversion was at best ambiguous and at worst absent (Yoshimura, 2002; Harris, 1980). Finally, recent experiments with inverting goggles by Linden et al. have shown definitively that **KH** is false and that the visual image does not re-invert even upon the return of sensorimotor skill (Linden, Kallenbach, Heinecke, Singer, & Goebel, 1999). In the words of the experimenters themselves:

> Subjects, who wore prism- and mirror-inverting spectacles over periods of six to

> ten days, showed a rapid visuomotor adaptation and were able to interact correctly with the surrounding world after a few days. This adaptation was not accompanied by a return of upright vision, as assessed by introspection, reading performance, and the extraction of three-dimensional shape from shading.... This dissociation of visuomotor and perceptual adaptation contradicts established views about the changes brought about by inversions of visual input (Linden et al., 1999, p. 480).

Unlike Kohler, Linden et al. were explicitly concerned with testing **KH** and determining whether or not any visual re-inversion occurs with the return of sensorimotor competency. They were also concerned with something more specific than the return of the ambiguous "veridicality" that Kohler and Noë discuss. The restoration of veridicality, after all, could just consist in the return of fast reliable judgments of relative vertical position without any re-inversion of what the subject *sees*. Most behavioral tests test for veridicality—i.e., for the reliability of judgments about egocentric spatial location of a target and/or the capacity for skillful action with respect to a target—but most tests fail to distinguish between veridicality that is due to visual content that is right-side up and veridicality that is due to knowing how to interpret and make use of an altered visual image.

There is strong evidence that veridicality can be restored without re-inversion of the visual image: both Kohler and Linden et al. report that subjects quickly regain the capacity for skilled movement—walking, biking, skiing, etc. However, *by their own testimony* these subjects retain inverted visual content (Linden et al., 1999 p. 475). Kohler writes that Dr. von Kundratitz was biking by the fourth day of the experiment and skiing by the sixth, yet, "During all this time, however, his perceptions were only sporadically rightside up." Similarly, "During a simulated fencing match, the subject parried all blows correctly, even though the opponent was seen upside-down." (Kohler, 1961, p. 31).

Further, Linden et al. did the obvious thing and actually *asked* subjects about re-inversion.

No subject reported a return of upright vision during the ten-day span of the experiment. These introspective reports should be evidence enough that no visual re-inversion occurs: there is no reason to think that subjects might *mis*-report that their visual images are still altered when they are not.

In case introspective reports were not enough, however, Linden et al. also used another task meant to get at their subjects' *specifically visual* content by getting around the content of the judgments about the orientation of targets that subjects make on the basis of what they see. In a modification of a task used by Ramachandran (in Ramachandran, 1988), Linden et al. gave subjects a visual test that required them to extract shape and depth information from shading. The visual test involves circles on a neutral gray backgrounds that are filled with shading gradients that are either black at the top and fade down to white or vice-versa. Subjects perceive the circles that are white at the top as convexities and the circles that are black at the top as concavities.[2] Ramachandran has shown that responses in this task depend crucially on what the subject judges the position of the light source to be and that, in the absence of controverting information, the light source is assumed to be at the top of the scene.

Linden et al. found that subjects wearing inverting goggles showed consistent inversion of their responses on this task from baseline throughout the experiment. After donning inverting goggles, subjects immediately judged circles concave that they had previously judged convex, and vice-versa. This inversion of response was consistent throughout the entire experiment, and reversed itself only upon removing the goggles (Linden et al., 1999 p479). This is strong evidence that the visual field remained effectively inverted through the entire task, despite the return of sensorimotor competency. As such, the evidence is strong that **KH** is false.

4 Objections and Replies

4.1 Perceptual adaptation occurs in other conditions

It might be objected that although Linden et al. did not show perceptual adaptation, other studies did show adaptation. Taylor was concerned with perceptual adaptation, and does present first-person accounts that suggest that it does occur. Similarly, both Kohler and Stratton do present evidence that some perceptual adaptation occurs, as do Harris and Yoshimura—even if in each of these cases the adaptation is intermittent and incomplete. Hence, the objection runs, just because Linden et al. could not find re-inversion does not mean that re-inversion does not occur.

But this objection misses the point of appeal to empirical work. As the Taylor quote above emphasizes, enactivism does not just predict the occurrence of perceptual adaptation. Rather, it predicts that adaptation will occur *precisely when* sensorimotor adaptation occurs. Again, the enactivist *must* predict this, for the enactivist claim is just that possession of sensorimotor knowledge constitutes the perceptual capacity.

Hence, what is important about Linden et al. is not just that they failed to find perceptual adaptation. It is that they failed to find perceptual adaptation even though sensorimotor adaptation had occurred. That shouldn't be possible on the enactivist account. That it happened is a serious mark against the enactivist.

Similarly, it is not an objection to Linden et al. that they did not have subjects wear the glasses for longer, or that perceptual adaptation might have eventually occurred. It may have—indeed, the evidence suggests that it eventually would have. But again, this would mean that perceptual adaptation happens *after*, rather than concurrent with, the return of sensorimotor knowledge. That is again evidence against the enactivist account.

4.2 Enactivism is not an Empirical Thesis

It might be objected that, after all, enactivism does not make any empirical commitments and is therefore immune to refutation by experiments like Linden et al.'s. For obvious reasons, this objection is rarely made directly. For one, even if it was successful, denying that enactivism has empirical content would be a striking victory for enactivism's opponents. Taking the possibility of empirical confirmation off the table is to give up on what many people find compelling about enactivism.

For another, the objection is simply false. Enactivism does carry empirical commitments. Sensorimotor knowledge can be studied. Perception can be studied. One good way to get at both is through the manipulation of sensory input. It makes sense to say that something more, or less, or different than sensorimotor knowledge might be required for perception. As the Taylor quote emphasized, this gives empirical content to enactivism. Like it or not, then, enactivists have made a claim with empirical content, and one that is open to empirical refutation.

Alas, not all denials are so straightforward. There are a number of tempting responses to Linden et al. that are *effectively* a denial of empirical content. As they have similar flaws, it is useful to consider variants of them together.

4.2.1 Definitional Version

The enactivist might claim that the failure of Linden et al.'s subjects to perceptually adapt just counts as *evidence that* sensorimotor adaptation was incomplete. "*Something* must be missing," the objection goes, "for if there was sensorimotor adaptation, then perceptual adaptation would follow." On this reading, full sensorimotor adaptation must result in correct perception and action *by definition*; since correct perception did not return, sensorimotor adaptation must have been lacking as well.

Note first that even if true, this removes enactivism from empirical test. Theories don't get

empirical content by predicting something that is true by definition. Further, the objection is importantly false. Enactivism was attractive precisely because we have an independent handle on the notion of sensorimotor contingencies. This is why enactivism appeared to be open to empirical test in the first place: sensorimotor contingencies sounded like the sort of thing that we could study independent of perception to see if they linked up with perceptual ability. To be told that they are linked as a matter of definition is to rob enactivism of much of its interesting and distinctive content.

This objection does highlight one important point. Nothing I have said logically compels the enactivist to abandon her position. As we have known since Quine, no one is *ever* logically compelled to abandon any scientific position on the weight of empirical evidence alone. Even if enactivism is dead wrong, enactivists can choose—just like any theory can choose—to create an ever more elaborate superstructure of hedges around the false core of a degenerate research program (Lakatos, 1970). Part of these hedges may well include redefining "sensorimotor adaptation" in the manner suggested by the definitional response. Empirical evidence speaks only against a position that has opened itself to empirical test, not a position that is being preserved at all cost.

4.2.2 Inconceivability Version

A closely related objection claims that visual *inversion* is a conceptual impossibility. This is usually defended by appeal to an extremely strong thesis about the transparency of visual experience. It would be impossible for someone to see *that* something was up above (the line goes) by seeing it on the 'bottom' of their 'visual field'. To see it on top just is—to see it as up on top! Strong transparency is false; we cannot put a wedge between what we see and how it is presented to us. To do so would make you a Cartesian/sense data theorist/picture theorist/add favorite epithet here. Since Linden et al. certainly couldn't have shown the impossible, the objection runs, enactivism is preserved.

The conceptual version is an obvious nonstarter in the present context. Theories don't get empirical content by predicting the opposite of a meaningless claim; the conceptual version again amounts to nothing more than a denial of empirical content.

The response is also simply false. As noted above, subjects in Linden et al.'s and Kohler's experiments were happy to claim that their vision was different in some important, inversion-related way once they put on the goggles. I offer no positive story about what that experience might be like. It might be simple inversion of the visual field. It might be more like viewing the world while standing on your head, or the complicated phenomenology of adapting to bifocals.[3] It might be something even harder to describe.[4]

4.2.3 Evidential Version

The most subtle form of this objection—the *evidential version*—admits that full visual inversion is possible, but denies that we could ever have evidence that someone has undergone it. For if subjects are drawing the correct conclusions from their visual experience and using words in the correct way—to pick out facts about the world, not about their visual experience—then they will remain indistinguishable from ordinary, non-inverted subjects. Hence, Linden et al. must be flawed, for one cannot show something for which there could be no evidence.

Again, to deny that we could gain evidence distinguishing the prediction of enactivism from its negation is simply to deny that enactivism has empirical content. Again, the evidential version is independently implausible.

Consider first a flawed thought experiment that seems to support the objection. Suppose that vision was the *only* sense modality. Suppose we then put on inverting goggles. Would we be able to sensibly assert that vision had been inverted? Maybe not. Maybe in that case, the only way we could fix the reference of the terms 'up' and 'down' would be by relative positions in the visual field; as such, talking about up and down being visually

inverted wouldn't make any sense. Similarly so when we try to imagine a case where we have all of our sensory modalities but all of them are inverted. Perhaps in all of these cases, the enactivist might concede, it still makes sense to talk of vision being inverted. But how could you tell?

The problem with this is that subjects *in standard experiments* were not in that situation. They had extra information: namely, what things were like before the switch. And they can fix the referent of terms like 'up' and 'down' by reference to their previous experience and to non-inverted modalities to let us know that vision remains inverted.

This is the key to making talk of visual inversion meaningful. Suppose I want to claim that what I used to see on the top I now see on the bottom, and vice versa. I can fix the meanings of 'up' and 'down' by reference to my *non-inverted* proprioceptive sense. Suitably glossed, then, my claim is that "What I used to see as (closer to where I feel my head) I now see as (closer to where I feel my toes)." I might assert this even though exactly the same things certainly *look* as if they were next to my seen left hand before and after I put on the goggles. The possibility of cross-modal comparison is always present, and is enough to allow meaningful talk about inversion of the visual image.[5]

4.3 Insufficient adaptation

A more promising sort of objection tries to identify some sensorimotor knowledge ϕ lacking in Linden et al.'s subjects, and then claim that ϕ is actually a necessary condition for correct perception. If successful, this would be more satisfying then the objection in 4.2.1, for it would point to some test of enactivism that we might specify independently of a pre-existing commitment to the doctrine.

Of course, the devil is in the details. First, note that some determinate ϕ must be specified—otherwise this would just be a version of the objection in section 4.2.1. I suspect there is no satisfying ϕ that will be found. When a subject wearing inverting goggles is

skiing and riding bicycles and fencing, it is hard to see how there could enough by way of sensorimotor understanding that she still lacks that would make sense of the (seemingly vast) difference between a visual image that is *upside down* and a visual image that is *right-side up*.

Second, note that ϕ must be some missing sensorimotor knowledge, in the specific sense that the enactivist uses the term 'sensorimotor'. That is, subjects in Linden et al. must be missing some tacit knowledge of how the sensation they received would change given the motions of their bodies. It is important to keep this definition in mind. Is is not sufficient to find a ϕ specified using only sensory or motor terms. If enactivism has any distinctive content, it is that perception depends on a very specific kind of relationship between sensory and motor capacities. Just claiming, for example, that perception relies on some sensory capacities and some motor capacities—or, even, that subjects in Linden et al. lacked thus-and-such sensory or motor capacities—would not be enough to establish enactivism. For many theories of perception treat at least some sensory and motor capacities as necessary for perception.[6] Nearly all contemporary forms of functionalism, for example, partially anchor mental processes in sensation and behavior. If ϕ is to support enactivism, therefore, it must talk only of the knowledge of how sensory input would change given motion, not of any old sensory and motor processes.

Put this way, it is hard to see what sensorimotor knowledge could be lacking in Linden et al.'s subjects. Consider again the shape from shading task. Subjects are confronted with very basic stimuli—circles filled with simple shaded gradients. It does not take much to learn how the sensory input from these circles might vary with different eye movements. Indeed, the identification task included circles of both gradient orientations—which means that both before and after putting on the goggles, subjects had familiarity with qualitatively identical sets of stimuli. Of course, given the same circle, one takes in different information with the same movements depending on whether one has goggles on

or not. But there is no reason to suppose that Linden et al.'s subjects were confused or missing that sort of knowledge.

Of course might be other sorts of knowledge one lacks—trivially, subjects lack the ability to re-identify circles seen pre-goggles as looking-concave or looking-convex. But again, that is not the sort of knowledge the enactivist has claimed is necessary for perception. The sort of knowledge the enactivist has claimed is pretty simple to reacquire in the task Linden et al. focused on, and there is no evidence that subjects lacked it. As such, I cannot see any way of filling in ϕ that can be expected to help the enactivist.

5 Concluding Remarks

KH is false. Enactivism staked itself on **KH**; with the debunking of **KH**, enactivism should suffer as well. In some sense, that should not be surprising. Indeed, perhaps the most important lesson to take away from all of this is that *any* strong claim about the the response of the visual system to distortions of input is likely to be incorrect. If there is evidence for anything, it is that the visual system has a modular organization and that different modules adapt at different rates *for different reasons*. Some of this adaptation may even be simultaneous with the return of sensorimotor competency, and may even be the best explanation of that adaptation. I happen to think so—so I think some kind of *weak* enactivism is almost certainly true. But as we've seen, sensorimotor knowledge is not the explanation of *every* effect.

The failure of **KH** should stand as a cautionary tale for those who would make so much about vision depend so few parameters. We will tease out the many and varied determinants of visual experience; before we do so, however, we will have to kick the Kohler habit.[7]

Notes

[1]Other philosophers who adopt a similar approach include Susan Hurley and Philip Pettit. See Hurley, 1998, Pettit, 2003, Pettit, 2004

[2]There was also a second, similar visual test involving sets of two white lines and two black lines forming squares on a neutral gray background. As in the first test, subjects perceive squares with a white line on the top as protruding from the background and perceive squares with a black line at the top as being recessed into the background.

[3]Thanks to Gideon Rosen and Dave Hilbert, respectively, for the examples.

[4] Noë argues that subjects who don goggles are "experientially blind" until they adapt, and thus their visual experience is chaotic and unintelligible (Noë, 2004, p. 3). I suspect that claims of Experiential blindness are the deep root of this sort of objection. Kohler's subjects did provide some lurid descriptions of their experience upon donning and removing their inverting goggles; as the above emphasizes, however, some of Kohler's subjects did find it intelligible to report that their vision was inverted. Further, Linden et al.'s subjects reported nothing like the confused and chaotic disrupted vision posited by Noë. They write:

> Subjects felt dizzy for the first few hours with the inverting mirror spectacles, and dizziness returned for about half an hour when they had taken off the spectacles at the end of the experiment. This was the only abnormal aftereffect that the return to normal vision had on the subjects (Linden et al., 1999, p. 478).

[5]This is similar to the response given by Harris, 1980.

[6]As Gideon Rosen has pointed out to me, not *all* philosophical theories have done so, so it is not as if this weaker version is entirely trivial. However, this fact alone would not be sufficient to distinguish enactivism from many other theories of perception.

[7]Thanks to Gideon Rosen, Alva Noë, and audiences at Princeton University and ASSC 10 for useful feedback on an earlier version of this paper. Special thanks is owed to Gabriel Love, with whom I had many very useful conversations on the topic, and who helped me present a portion of the paper at ASSC 10.

6 References

Harris, C. (1980). Insight or out of sight?: Two examples of perceptual plasticity in the human adult. In C. Harris (Ed.), *Visual coding and adaptability* (pp. 95–149). Hillsdale: Lawrence Erlbaum.

Hurley, S. (1998). *Consciousness in action*. Cambridge: Harvard University Press.

Kohler, I. (1961). Experiments with goggles. *Scientific American*, *206*, 62–72.

Kohler, I. (1964). The formation and transformation of the perceptual world. *Psychological Issues*, *3*, 1–173.

Lakatos, I. (1970). Falsification and the methodology of scientific research programmes. In I. Lakatos, & A. Musgrave (Eds.), *Criticism and the growth of knowledge*. Cambridge: Cambridge University Press.

Linden, D. E., Kallenbach, U., Heinecke, A., Singer, W., & Goebel, R. (1999). The myth of upright vision. A psychophysical and functional imaging study of adaptation to inverting spectacles. *Perception*, *28*, 469–81.

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

O'Regan, J. K., & Noë, A. (2001). A sensorimotor approach to vision and visual consciousness. *Behavioral and Brain Sciences*, *24*(5), 939–73.

Pettit, P. (2003). Looks as powers. *Noûs: Philosophical Issues*, *13*, 221–52.

Pettit, P. (2004). Motion blindness and the knowledge argument. In *There's something about mary: Essays on phenomenal consciousness and frank jackson's knowledge argument* (pp. 105–42). Cambridge: MIT Press.

Ramachandran, V. (1988). Perception of shape from shading. *Nature*, *331*, 163–166.

Stratton, G. (1897). Vision without inversion of the retinal image. *Psychological Review*, *4*, 341–60 and 463–81.

Taylor, J. G. (1963). *The behavioral basis of perception*. New Haven: Yale University Press.

Yoshimura, H. (2002). Re-acquisition of upright vision while wearing visually left-right reversing goggles. *Japanese Psychological Research: Short Report*, *44*(4), 228–233.