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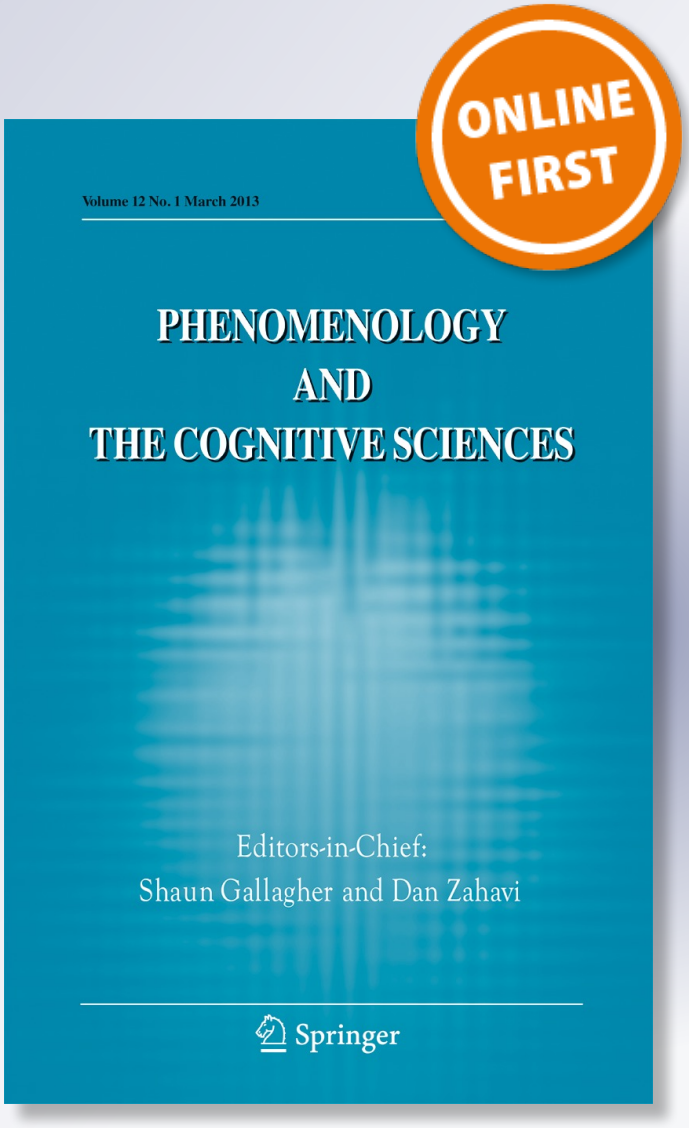


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# Through the inverting glass: first-person observations on spatial vision and imagery

**Jan Degenaar**



**Abstract** Experience with inverting glasses reveals key factors of spatial vision. Interpretations of the literature based on the metaphor of a "visual image" have raised the question whether visual experience with inverting glasses remains inverted or whether it may turn back to normal after adaptation to the glasses. Here, I report on my experience with left/right inverting glasses and argue that a more fine-grained sensorimotor analysis can resolve the issue. Crucially, inverting glasses introduce a conflict at the very heart of spatial vision. At first, the experience of visual direction grounded in head movements differs from visual experience grounded in eye movements. During adaptation, this difference disappears, and one may learn to see without conflict where objects are located (this took me 123 h of practice). The momentary experience became once again integrated within the larger flow of visual exploration involving head movements, a change of experience that was abrupt and comparable to a Gestalt switch. The resulting experience remains different from normal vision, and I argue that this difference can be understood in sensorimotor terms. I describe how adaptation to inverting glasses is further reflected in mental imagery, supporting the idea that imagery is grounded in sensorimotor engagement with the environment as well.

**Keywords** Inverting glasses · Visual stability · Spatial vision · Imagery · Sensorimotor engagement

## Introduction

As we look around, we effortlessly see where objects are located and we perceive the world as a stable stage ready to be explored. Vision is so familiar and it seems so simple that we tend to overlook how it depends on the complex interplay of eye movements,

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head movements, and retinal stimulation. We cannot normally differentiate between the factors working together to yield a coherent visual experience, as first-person reflection on vision is hampered by the perfection of our visual skills. Inverting glasses provide a partial remedy. By means of lenses, mirrors, or prisms, the light reaching the eyes can be altered in such a way that left and right and/or above and below are inverted. This helps to explore the nature of visual orientation and stability, for it removes the veil of familiarity and it can enable us to disentangle what is usually bound together. Inverting glasses introduce systematic changes in the relation of retinal stimulation to action, the environment, and the other senses, allowing us to investigate how these changes affect visual experience. Consequently, vision with inverting glasses can provide a window into the determinants of spatial visual experience.

How should we understand the experiences of vision with inverting glasses? On a traditional conception, visual experience is thought of in terms of the possession of a "visual image," an inner model or representation of the environment inside the head. On this view, the initial consequence of wearing inverting glasses is the inversion of this image. As one adapts to wearing inverting glasses, one of two things may then happen: visual experience may remain inverted, or it may re-invert under influence of interaction with the environment. When interpreted in terms of this visual image metaphor of vision, some reports suggest that after adaptation visual experience with inverting glasses re-inverts to become similar to vision without inverting glasses (e.g., Taylor 1962; Kohler 1964a). Other reports suggest that experience does not turn back to normal in this sense (e.g., Stratton 1897). However, it is uncertain whether these interpretations reflect fundamental differences in the experiences resulting from adaptation to inverting glasses. Possibly the differences are an artifact of the traditional interpretational framework: when forced into descriptions in terms of visual images, a difference in emphasis on similarities or differences with normal vision may get amplified into seemingly huge differences in experience.

A prominent alternative to the traditional conception is provided by the sensorimotor account of visual experience (e.g., O'Regan and Noë 2001; Hurley and Noë 2003; O'Regan 2011). Rather than viewing visual experience as depending on an image or model inside the head, this account claims that experience lies in our skillful bodily engagement with the environment. This engagement is specified in terms of the ways in which sensory stimulation depends on the activity of the perceiver, the *sensorimotor dependencies* obtaining in the perceiver's interaction with the surrounding world (O'Regan and Noë 2001). Consider for example the visual experience of an object standing at some distance to its background: by moving sideways, occluded parts of the background come into view, and on approach the object expands in one's visual field. The sensorimotor account explains the experience of the spatial layout of objects in terms of such larger patterns of sensorimotor dependencies. On this account, to see an object at some distance from its background is to be familiar with the sensory consequences that are to be expected if one were to move; it is to be attuned to the obtaining sensorimotor patterns.

The view that visual experience lies in the perceiver's sensorimotor engagement with the environment provides a fresh perspective on vision with inverting glasses. Instead of positing a unitary visual image as the basis for experience, the

sensorimotor account claims that visual experience lies in the exercise of a whole range of perceptual capacities (O'Regan and Noë 2001). It is not just that full-blown visual interactions with the environment depend on different capacities, such as the capacity to see colors, to read texts, to recognize facial expressions, to see shapes and shading. If we consider what we may call a single capacity of spatial vision, such as the apparently simple capacity to perceive the location of an object, it may turn out that this capacity is an amalgam of a whole range of sensorimotor skills. Consider the experience of something as being on the left: the location of the object may be experienced when the perceiver is familiar with the sensory consequences of eye movements, of head movements, or of movements of the whole body. Different sensorimotor regularities may form the basis for the same perceptual judgment. Inverting glasses transform the sensorimotor patterns implied in spatial vision, to some extent disrupting visual experience (Noë 2004). Rather than analyzing this disruption as an inversion of a visual image, the sensorimotor account focuses on the ways in which inverting glasses transform some of the sensorimotor patterns associated with visual experience. Subsequent perceptual adaptation is then analyzed as a matter of re-acquiring various sensorimotor skills rather than as a unitary re-inversion of a visual image. If the sensorimotor account is right, then the changes in sensorimotor patterns should hold the key to an accurate description of the changes of experience brought about by the wearing of inverting glasses (e.g., O'Regan and Noë 2001; Hurley and Noë 2003; O'Regan 2011).

In this paper, I shall describe my experiences with wearing left/right inverting glasses and I shall draw on these experiences to compare a sensorimotor account with descriptions in terms of visual images. First, I shall discuss some classical studies on vision with inverting glasses ("A puzzle from earlier studies"). Rather than providing a full review of the literature, I shall explain how previous reports raise questions about the possible "re-inversion" of experience after adaptation to inverting glasses. To sketch the background of my findings, I will then describe the glasses I used and the general course of the experiment ("Donning the glasses"). Subsequently, I provide a description and interpretation of the main findings, relating to visual stability ("Visual stability"), the experience of left and right ("The experience of left and right"), and visual memory or imagery ("Mental imagery"). I conclude that inverting glasses introduce a conflict at the very heart of spatial vision, that a sensorimotor analysis—recognizing the role of eye movements and head movements—is very useful for an adequate description of the resulting visual phenomenology, and that the conflict between visual image-based interpretations of the literature can be resolved by this analysis ("Conclusions").

## A puzzle from earlier studies

In a pioneering study on "vision without inversion of the retinal image," George M. Stratton (1896, 1897) used lenses that inverted both the left/right and the up/down orientation of the light entering his eyes. He wore these lenses full-time for several days: 3 days in the first experiment, 8 days in the second (he used the lenses for one eye; the other eye was covered). In the beginning

of the experiment, the hand that would feel as on the lower right, where it was, would visually appear as if it were at the upper left. There thus was a conflict between vision and touch, and the visual appearance of things no longer conformed to their actual location. Frequent inadequate behavior was the predictable result, although Stratton did learn to cope with the glasses. But the most interesting thing was that as the experiment progressed, experience itself started to change. Stratton reports that later in the experiment "the limbs began actually to feel in the place where the new visual perception reported them to be" (Stratton 1896, p. 615).

This may seem to suggest that the conflict between touch and sight was resolved as a result of the adaptation of the felt position of the limbs to visual experience. If touch adapts to vision, we may suppose that visual experience was still inverted while the experience of the body had adapted to the new mode of vision. But Stratton reports that in a sense, "upright vision" was in fact restored, as vision and touch were once again experienced as harmonious, and he concludes that upright vision is possible without the usual inversion of the retinal image:

> "The inverted position of the retinal image is, therefore, not essential to upright vision, for it is not essential to a harmony between touch and sight, which in the final analysis, is the real meaning of upright vision. For some visual objects may be inverted with respect to other visual objects, but the whole system of visual objects can never by itself be either inverted or upright. It could be inverted or upright only with respect to certain nonvisual experiences with which I might compare my visual system—in other words, with respect to my tactual or motor perceptions." (Stratton 1897, pp. 475–476)

We should not conclude that the spatial phenomenology of the reported upright vision is similar to the pre-experimental upright vision. The reason for that is that upright vision, for Stratton, simply means that vision and touch are in agreement—that you see things where you feel them. Moreover, Stratton suggests that perhaps neither sight adapts exclusively to touch, nor touch exclusively to sight (Stratton 1897, p. 472). In order to say more about the resulting visual phenomenology we must consider a third crucial factor in Stratton's report, besides touch and sight, namely *visual memory*. Stratton notes that the "memory images" from before the experiment "preserve a spatial arrangement whose lines of direction were opposed to those of the actual field of view" (Stratton 1897, p. 472). This testifies to nontrivial differences between the 'upright vision' before wearing the glasses and the reported 'upright vision' after adaptation to the glasses. Although Stratton characterized his experience with inverting glasses as eventually "upright," his comparison of vision with visual memory suggests that visual experience remained importantly different from normal upright vision (see also Harris 1965).[1]

[1] Although Stratton's report does not support the view that after adaptation to inverting glasses the experienced visual direction of objects "flips around," it is usually read as a report of perceptual adaptation of some sort. Some more recent studies, in contrast, have found no evidence for altered perceptual experience (e.g., Linden et al. 1999), and in some cases proprioceptive adaptation has been found to dominate (e.g., Harris 1965). Note that I do not aim to discuss the genuinely different findings that can be found in the literature on inverting glasses: I shall merely focus at apparent differences that in my view are an artefact of a mistaken interpretation of vision with inverting glasses.

Some subsequent findings, in contrast, seem to go against the idea that the spatial phenomenology of vision with inverting devices remains different after adaptation.[2] In *The Behavioral Basis of Perception*, James G. Taylor (1962) reports an experiment in which a subject wore left/right inverting glasses part-time. At the eighth day of the experiment, the subject visually experienced a chair "as being both on the side where it was in contact with his body and on the opposite side." The experience of the chair, which in reality stood on the right, was "like the simultaneous perception of an object and its mirror image, although in this case the chair on the right was rather ghost-like" (Taylor 1962, p. 202).[3] The occurrence of these curious experiences did not last long, as visual experience adapted towards accordance with the actual location of objects. This adaptation suggests that the ghostly experiences strengthen, and gradually lose their ghostly appearance until they eventually take over visual experience. Given that these experiences are the "re-inversion" of the artificially inverted vision, we may suspect that this would leave the subject with an experience similar to the normal visual experience.

If we were to conceive of visual phenomenology in terms of having a visual image, there would appear to be a conflict between the reports of Stratton and Taylor. Stratton's report would then suggest that the subjective visual image remains inverted after adaptation to inverting glasses, while Taylor's report would suggest that the visual image turns back to normal. This apparent conflict may of course be due to differences between the experiments or they may reflect inter-individual differences in visual phenomenology. In some circumstances or in some people, visual experience may be more prone to change during adaptation to inverting glasses. But it is also possible that a more fine-grained analysis can help to resolve the conflict.

The need for a more subtle analysis is suggested by the finding that different aspects of visual experience may adapt independently. For example, it has been reported that after adaptation to inverting glasses, when much of the world was reported as having its actual orientation again, other parts, such as letters, still seemed to be inverted (Kohler 1964b, p. 155). If we were to conceive of visual experience in terms of images, we may wonder what kind of an image it would be that would have such exotic properties as to allow for partial inversion (Taylor 1964, p. 73). For example, how can the words on a signpost appear inverted if they start at one side of the signpost and end at the other, if we believe that the image of the signpost is not inverted? Instead it seems more parsimonious to accept that visual experience is not like a unitary image that may or may not be inverted. Perhaps visual experience would better be viewed in terms of the various subsystems or perceptual skills that are brought to bear on the environment, as various authors have argued (e.g., Taylor 1962, p. 207; O'Regan 2011).

However, if we view perceptual experience in terms of sensorimotor skills rather than in terms of having a visual image, the question still remains how we can reconcile the findings of Stratton and Taylor. After all, it is not the case that the

[2] Throughout this paper, I focus at spatial aspects of experience. Note that visual inversion can change other aspects of visual experience as well, such as the familiarity of objects, or in the case of inversions of above and below, the experience of facial expressions (see Dolezal 1982; Bredlau 2011).

[3] A similar report can be found in the work of Kohler, who writes that a subject, after wearing left/right inverting glasses, "was capable of seeing two points of light when only one was presented (and this happened even monocularly)" (Kohler 1964b, p. 161).

one reports, say, inverted letters while the other reports a noninverted rest of the world. A sensorimotor account offers a possible solution, for in this account there is room for ambiguity within spatial experience: some capacities of spatial vision may be selectively disrupted by wearing inverting glasses, while others remain relatively unperturbed. As visual capacities are regained, we may then expect that accurate visual experience is recovered, while at the same time differences in experience remain, reflecting the sensorimotor differences introduced by the inverting glasses. While one author may have been more impressed by the similarities between normal vision and vision with inverting glasses, the other may have been more taken by the differences, resulting in the apparent conflict between the reports. As we shall see below, this resolution of the conflict is not merely a conceptual possibility. I shall argue that on the basis of careful reflection on vision with inverting glasses we can indeed resolve the conflict and get a better view on spatial visual phenomenology.

## Donning the glasses

The glasses I used were a simple device with a right-angled prism placed in front of each eye. This resulted in a left/right inversion of the light coming from the visual field, so that on first use of the glasses, distal stimuli at the left side within the field of vision subjectively appear as being on the right and vice versa. At the same time, moving the head to the right brings in view the objects at the right, as during normal vision. Looking straight ahead, what visually appears as being at the right therefore goes out of view first when turning the head to the right. When one is not used to the inverting glasses, one has to shift one's head to the left in order to look behind the side of an object that visually appears as being on the right.

While inverting glasses do not alter the relation between head movements and the part of the world that is seen (the distal field of vision), they do alter the relation between head movements and the proximal stimulation. In this respect, the consequences of wearing inverting glasses are the opposite for eye movements. When defined in relation to the distal stimulus, inverting glasses do alter the relation between eye movements and focal vision—the place of highest resolution in the center of the view of the eyes. For the proximal stimulus, in contrast, inverting glasses leave unaltered how eye movements relate to retinal stimulation: whether or not one is wearing inverting glasses, the light falling on the left side of the retina can be brought to focal vision by turning one's eyes towards the right. As long as the head remains stationary, visual exploration of objects by means of eye movements therefore provides no difficulties. For a schematic illustration of prominent consequences of using the glasses, see Fig. 1.

I wore the glasses over my normal glasses, wearing a hood against false light. The glasses strongly restricted my visual field. At arm's length, the scope was about two hand's wide (20.5° of visual angle), with the width of one hand of stereoscopic vision. The vertical reach of sight was much more generous (31° of visual angle). As a result of my limited scope, I had to make scanning movements with my head to acquire a reasonably rich impression of my surroundings. When outside, I used a white stick to signal my self-imposed visual handicap.

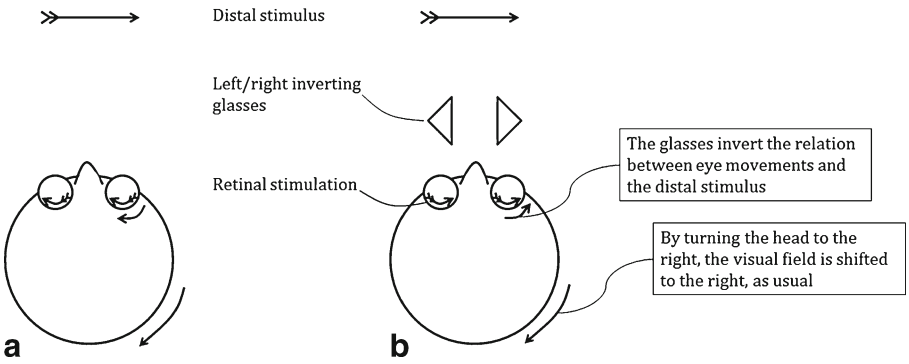


**Fig. 1** Schema illustrating consequences of the left/right inverting glasses (**b**), compared with vision without inverting glasses (**a**). Note that the glasses invert the relation between the distal stimulus and eye movement (e.g., with inverting glasses objects at the right can be brought into focal vision by an eye movement towards the left), but that with eyes aimed forwards, the direction of the head determines the center of the distal visual field as normal (e.g., head movement towards the right brings the right side of the visual field in central view). Further note that, while the relation between retinal stimulation and the distal stimulus is altered, the relation between retinal stimulation and eye movements is unaltered (see text)

I had no fixed scheme for wearing the glasses. On some days, I did not have the opportunity to wear them at all, but most evenings I did. In the 31 days of using the glasses, I wore them on average 4 h and 8 min/day, resulting in a total of over 128 h at the 31st day of wearing the glasses (43 days after starting the experiment, due to the days that I did not wear the glasses). On some occasions, my activity was rather limited, especially when I watched movies, which required eye movements and minor head movements only. Other activities I engaged in include typing, cooking, doing the dishes, playing the board game *go* with a friend, and going for a walk. I started walking outside only after 15 days of wearing the glasses. As in the experiments of Stratton (1896, 1897) and Kohler (1964b), I used no systematic training program. With systematic training, quicker adaptation could have been expected (Taylor 1962).

On the first day of wearing the glasses I experienced a lack of visual stability and I saw double, except at arm's length. After a few hours, I suddenly experienced nausea and I vomited, after which I felt weak for the rest of the evening. I therefore decided to take my time to get used to the glasses. When I got the opportunity to wear the glasses again some days later, I engaged primarily in simple activities, such as watching movies. Soon I found I could walk around (though clumsily) and I was not sick at any further point during the experiment. By the third day, the reach of proper stereovision was already much larger. I could effortlessly see the other side of the room and even the houses at the other side of the street.

I often reached in the wrong direction, even when I knew where objects in my room were located. Vision tends to overrule knowledge, and to a certain extent, even habits are cancelled or transformed. A notable behavioral impairment expressed itself when I attempted to reposition a cup that was standing too close to the edge of a table. It was almost impossible to find the right direction. Trying to correct the movement, I instead altered it in the wrong way. Even days later, cutting tomatoes still had a similar effect: the appropriate orientation of the knife was almost impossible to bring about.

When I took off the inverting glasses after I had worn them for some hours, head movements disrupted visual stability. These after-effects, which can be considered clear signs of perceptual reorganization, often lasted for over half an hour. Some of the mornings when I woke up after wearing the glasses on the preceding day my head felt heavy. During the course of the experiment, I became used to the alternation of vision with and without inverting glasses, and the disruption of visual stability and the experience of a heavy head both decreased in strength.

A few times, I also experienced more striking after-effects. For example, on the 8th day, even without the glasses, I noticed that I sometimes moved the mouse of my computer in the wrong direction. On the afternoon of the 10th day, while reading an article without wearing the glasses, I moved my hand to turn the page and found myself surprised at the sight. I had not anticipated that turning the page with my right hand would look like that; I had rather expected the other hand to turn, as if I were looking through inverting glasses so that my right hand would appear to be at the left. I did not experience other disturbing after-effects during the rest of the experiment.

My behavioral skills when wearing the glasses gradually increased. On the 4th day, I cooked a simple meal, which I would not even have tried at the beginning of the experiment. I also developed strategies for walking: by turning my head towards the direction in which I had to go, I somehow managed to automatically correct my way. This way I zigzagged through the hallway, and throughout the experiment my path got straighter and straighter. On the 1st and the 12th day, I tested my skills by tracing a circle with a pencil with my eyes open. The result confirmed a serious increase of skill, approaching the level reached without inverting glasses, as can be seen in Fig. 2.

After the 15th day of wearing the glasses (67 h), I started walking outside, using my white stick for safety. The first time it took me about an hour to walk home from my office at the faculty of philosophy (without the glasses it takes me less than half an hour). After eight more days of practice, it took me less than 35 min. But even then I had remarkably limited awareness of the side of the road I was on. On narrow sidewalks this could be slightly disturbing, because of the noise of cars whizzing by at the side where I didn't expect them. Deliberate attention was typically required to judge to which side my visual field was directed. In general, awareness of the

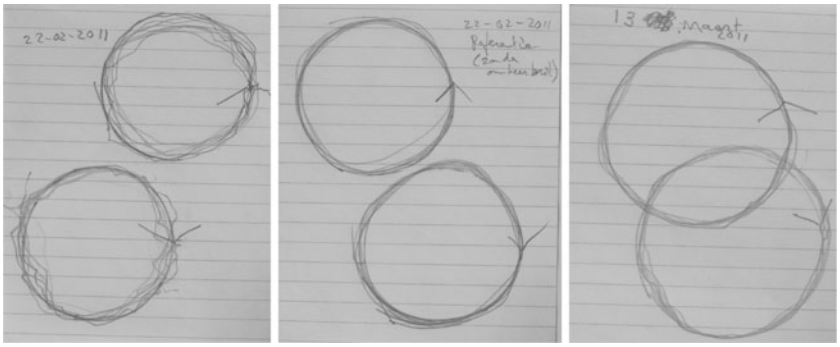


**Fig. 2** Test of my circle-tracing capacity. *Left*, circles traced while wearing inverting glasses at the first day of the experiment. *Middle*, circles traced at the same day without inverting glasses. *Right*, circles traced while wearing inverting glasses after 12 days of adaptation to inverting glasses. The higher circles are traced counter-clockwise and the lower circles clockwise

direction of my gaze was better while seated or standing still than while walking, and it increased over the days.

## Visual stability

Normally the world appears as something stable through which we can move and within which we can look around. One of the most prominent effects of wearing the left/right inverting glasses was the initial break-down of this visual stability; head movements resulted in an apparent movement of the scene. This is a very robust effect found throughout the literature (e.g., Stratton 1896; Taylor 1962; Kohler 1964a; Dolezal 1982), showing the direct relevance of action to perceptual experience (Taylor 1962; Hurley 1998). Here, I shall briefly describe the phenomenon of (regained) visual stability and draw consequences for pictorial descriptions of experience.

Without movement of the body or the head, the consequences of wearing inverting glasses for the experience of the environment are limited. Of course, things on the left seem to be located on the right and vice versa, and this does have some curious consequences. For example, I experienced that with letters appearing mirror-inverted, and with the inverted direction of reading, words lost their familiarity so that I often could read them only with effort. But in terms of more general aspects of spatial experience, things get more exciting only when one begins to move. For example, moving one's right hand visually appears as if one moves one's left hand, resulting in a strange conflict between vision and touch. In my experiment I have been mainly concerned with my visual experience of the environment (rather than with experiences of the outside world on the basis of other sense modalities, or with experiences of my body). The movements that make things interesting are then the movements of the head and the eyes.

Not being used to inverting glasses, the effect of turning my head was a serious disruption of visual stability: when I moved my head in the horizontal plane, the scene appeared to sweep in front of my eyes in the same direction as the head movement. This experience of the sweeping of the scene was not like the normal experience of watching a movie that is shot with a sideways moving camera, in which the images sweep across the movie screen. In case of the movie, one may effortlessly follow objects with one's eyes and head to get a good view of them. This ability to track objects was reduced when I moved my head while wearing the glasses. If I would attempt to track the sweeping scene by moving my head, the result would only be that the scene swept even stronger. What I was lacking was, as it were, a firm visual grasp of the environment.

While it is hard to describe my experience at this point, it is clear that a description of my experience in terms of visual images would be incomplete at best. The difference between unstable vision with inverting glasses and the normal experience of watching a movie shows that vision with inverting glasses cannot be captured by the metaphor of visual images. The movement of images does not normally imply a lack of grasp of the scene.

The experience as if the scene swept in front of my eyes could not be the result of the narrow scope of my field of view. For when I merely restricted my field of vision

this lead only to a subtle instability of visual experience, far less pronounced than with the inverting glasses. No doubt the main factor responsible for the disruption of visual stability was that the relation between retinal stimulation and the movement of my head had been altered. The breakdown of visual stability depends both on sensory stimulation and on movement-related factors. Thus the re-acquisition of visual stability must involve adaptation to the transformed sensory-motor relation.

During the course of the experiment, the intensity of the experience of the sweeping of the scene gradually decreased. It was on the 13th day of wearing the glasses, after over 57 h of wearing them, that I gained visual stability. Visual stability was quite absolute at this point, roughly as good as it is for me during normal vision. Interestingly, the onset of visual stability seemed quite abrupt, and it was with excitement that I noted this "perceptual breakthrough." At this point, I could look around without having a sense of sweeping, although fast movements of the head still disrupted visual stability. Walking impaired stability as well, perhaps due to the fact that it resulted in head movements that were not the consequence of actively turning my head. But when I was standing still I could move my head, and enjoy the experience of looking around in a stable world.

However, visual stability was still fragile. Not only did it break down when I moved too much or too quickly, there were also more specific causes for disturbance. One of these was tilting my head, which resulted in the experience as if the visual world rotated. Another was when I attempted to look over my shoulder. It turned out that, in sudden attempts to catch a glimpse of something behind me, I tended to direct my eyes in the way appropriate only to vision without inverting glasses. Without inverting glasses, moving my head to look over my shoulder automatically engages eye movements towards the same side. This tendency was still in place, but with inverting glasses this led to turning my eyes away from the parts of the scene that newly entered into view. As a result, my attempt to look over my shoulder often failed: I tended to turn my eyes in the wrong direction, so that a view of the objects behind me was not so quickly and automatically obtained as it usually is. A further consequence was that objects in focal view could not always be tracked with my gaze when I turned my head to look over my shoulder. The reason for this was that focal vision then tended to be at the periphery of my visual field and precisely at the side where objects disappeared from view. Looking over my shoulder then came with a breakdown of visual stability, even though visual stability was already becoming the standard when looking around at the scene in front of me.

In fact, as I later figured out, the relation between the direction of the eyes and visual stability can be confirmed without any inverting lenses. To try this, aim your head and eyes completely to the right. (It is especially important to turn your eyes to the right as far as possible, which is rather uncomfortable.) If you now turn your head to the left, while keeping your eyes turned completely to the right (this may not be easy, but it is crucial), you will be able to notice that visual stability breaks down. Even without inverting glasses you can then experience the breakdown of the possibility to keep track of objects, and appreciate that the lack of visual stability is an action-involving phenomenon different from cases where you experience moving images.

The return of visual stability can be described as a return of normal visual skills, such as the capacity to look over my shoulder, to track objects, or to keep objects in

view while turning my head. We have seen how limitations of descriptions in terms of visual images can be overcome by descriptions in terms of the skillful visual exploration of the environment. Rather than consisting in the possession of visual images, I suggest that the experience of visual stability results from having the right sensorimotor skills in place, leading to a firm visual grasp on the scene.

At this point, a proponent of the notion of a visual image might suggest that visual stability depends on the existence of a "stabilized" visual image inside the head, even if the stabilization may be partly due to the skillful tracking of the environment. But such a proposal would still have to account for both the lack of apparent movement of the visual scene, and for the change of experience as one looks around in an apparently stable world. For this, one has to appeal to concepts beyond the notion of a visual image. For example, one may propose that in the case of visual stability the perceiver must have a firm grasp of the alleged image. Or, for the case of visual instability, one may propose that the sense of movement is non-pictorial and that adaptation to inverting glasses involves the re-calibration of one's sense of movement. Yet, I would argue that, whatever its theoretical merits or problems, the notion of a visual image does not in itself suffice to describe visual experience. This becomes even clearer when we turn to the experience of visual direction.

## The experience of left and right

As long as I looked straight ahead, without moving my head, the effect of wearing the glasses could initially be described as a left/right inversion of visual experience. But as soon as I moved my head this description failed. One reason for this was the breakdown of visual stability, resulting in an experience notably different from a simple left/right inversion. After reaching visual stability, it became more natural to describe my experience as a dynamic left/right inversion. However, this description applied only to the experience of the relation between objects within my visual field. But there is more to visual experience than this. The experience of the location of objects can differ depending on the orientation of the visual field in relation to the body, even if the objects are in the same position within the visual field. For example, an object in the middle of one's visual field can appear to be located on one's right or on one's left, depending of the direction of one's head. As a result, even after reaching visual stability, a description of vision with inverting glasses in terms of a simple left/right inversion should be rejected, on the grounds that it fails to capture a crucial aspect of spatial vision.

Even in the beginning, I often had a clear notion of the direction in which I looked when I turned my head towards the left or the right, but this certainly was not always the case. In the first week of wearing the glasses, I noticed that I was not even always sure which hand I used in activities such as typing, during which I had to make scanning movements with my head. I could use the hand I saw, anchoring my action in sight, without a definite sense of using my left or right hand, and without explicit awareness of the direction of my view.

When I could look around without breakdown of visual stability (from the 13th day onward), the left/right inverted visual field appeared quite natural to me. This was so even though the objects that seemed to be on the right in my visual field

disappeared from sight first when I turned my head to the right. While seemingly natural, this was a curious inconsistency in visual experience, for what I visually experienced as being on the right in my visual field, immediately disappeared from sight when I moved my head towards what I (correctly) experienced as the right in the larger visual world.

My spatial experience at this stage can be elucidated by a description of the following event. On the 21st day (after 86 h of wearing the glasses), I had dinner in a house where I had never been before, entering the room wearing the inverting glasses. We talked, wined and dined, and by looking around I got an impression of the place. But when I first took off my glasses after dinner, I noticed that I had to adjust my idea of the room. For example, the couch that had appeared in front of me, moderately to the right, now turned out to be located next to me at my far right. This indicates awareness of the general direction of my visual field: I was well aware when I was looking to the right by moving my head to the right. At the same time, the experience reveals an inversion within my visual field: with my visual field aimed towards the right, objects that were on the right in my visual field appeared as if they were on the left in the visual field. I could have figured out the actual position of the couch if I had tried, but clearly I had not unreflectively registered its position.

Later, wearing the glasses again, at some point I looked at my legs while walking and noticed a curious phenomenon. The experience of the step I saw and the step I felt corresponded, but the curious thing was that, roughly speaking, vision was dominant. My right leg felt left. Apparently, my bodily feeling was firmly anchored in sight. It seems that experience tended towards coherence: my feeling of bodily position at this point conformed to my—eye movement dominated—visual experience. During most of the experiment no such altered bodily awareness occurred.[4] But it is worthwhile to describe the experience in some more detail.

To convey what my experience at this point was like, it will help to contrast my experience with the "harmony between touch and sight" mentioned by Stratton (1897), which he considered a sufficient condition for veridical (or "upright") visual experience. I must stress that the experience described above could not be described as veridical, not even on Stratton's terms. Given that I experienced the movement and direction of my head as usual, I had no difficulty in judging the incorrect nature of the tactile experience of my legs and the experience of their location within my visual field. While there was a considerable harmony between sight and the felt position of my legs, there certainly was no harmony between the sight of my legs and the felt head movements. Moreover, my awareness of the general direction of my view was still in conflict with the sight of the position of my legs within my view. For example, when I moved my head to the right, I was well aware that I looked to the right, but I

[4] By contrast, it has been argued that adaptation to inverting glasses may primarily involve changes of proprioceptive experience rather than visuomotor adaptation or changes of visual experience (e.g., Harris 1965). The experimental conditions are probably crucial to explain when primarily proprioceptive changes occur, and when changes are primarily visual. I would expect that where head movements are counteracted (as in most studies on which Harris relies), visual adaptation is counteracted, which may be favorable for proprioceptive adaptation. Furthermore, a high degree of visual attention to one's body may plausibly facilitate a change of proprioceptive experience. Throughout my experiment, I have been more concerned with the visual experience of the environment. Perhaps this explains why I have been more impressed by the inconsistencies *within* vision than by inconsistencies between different modalities, such as the fact that my left hand, which felt left, visually appeared to be on the right.

thereby looked in the direction of the leg that had appeared to be on the left (where it was felt to be as well). Thus only eye movement-based visual direction was in agreement with the (incorrect) proprioceptive experience of my legs, and my visual experience in as far as it was grounded in head movements was still conflicting with these experiences. For this reason, it would be more precise to speak not of the dominance of vision over felt bodily position but of the dominance of eye movement dominated visual experience over felt bodily position. Even though there was some (intermodal) harmony between touch and sight, my experience could not be described as veridical due to a lack of (intramodal) harmony within sight: spatial vision itself still lacked the coherence required for veridicality.

On the 30th day of wearing the glasses I decided to wear the glasses all day. I had an active day, walking on the beach and on the narrow paths winding through the dunes, and in the evening I settled down and engaged in careful observation. As I had already noticed before, calmly looking around by moving my head helped to see how objects are located in space: I could ground visual experience in the movement or direction of my head, or in the general direction of my view. I looked around the room attentively. This is when I noticed, after about 123 h of wearing the glasses, that objects finally and definitely visually appeared where they actually were. A few moments later, when I had not moved my head for a while, I fell back in the other way of experiencing the visual field again, so that the objects once again appeared to be in places where they were not actually located. But when I continued looking around again, by slowly moving my head, I could now see objects where they were. This was no longer just the case for the objects in central vision, where the experience of direction can be based on the direction of the head, but also for the objects to the left and to the right within my visual field.

In the room there were two sculptures of birds, and I could now see that their beaks were pointing to the upper left. I could follow this direction with my head and gaze, and I could accurately indicate the direction with my hand. Even when I let my gaze rest on an object for a while, avoiding head movements, I could now see what was the left side and what the right side. Let me stress that this was not merely the deliberate judgment of left and right—I could do that from the onset of the experiment—but the location as visually experienced. I could unthinkingly anticipate how movements would change my experience. The experience of the orientation of objects within my visual field was now in accordance with the experience of the general direction of my visual field during head movements; the inconsistency between the experience of the direction of my view and the apparent orientation within my visual field was gone. A good way to describe this would be to say that the seen objects were now included in the larger stream of vision: the appearance of the position of objects within my visual field fitted to the larger dynamics of visual experience during head movements.

In my case, this perceptual breakthrough was less spectacular than I had anticipated (cf. the description given by Taylor mentioned above). No curious experiences were apparent as of the simultaneous perception of objects and their ghost-like mirror image. In fact I had been more excited by the recovery of visual stability than by the distinctive change in the experience of left/right orientation. Only a few days earlier I had been doubtful about my chances at success. My behavior remained clumsy but I could cope, and I had feared that I would merely acquire competence in making do with visual impairment. But on the 30th day, when I could see where objects were,

this only seemed perfectly natural. It is significant that I could still switch to seeing the scene as inverted, in a way similar to the switching between different ways of seeing a Necker cube. Even if I would not move my eyes or head, the two alternative ways of experiencing the scene were subjectively different. In that sense the different ways of seeing the same scene may be described as different perceptual interpretations of the scene, but, like in the Gestalt switches of a Necker cube, this was nothing like a pictorial inversion.

A way to describe the alteration of experience would be as follows. With some effort I could still feel to which side I moved my eyes, but the visual significance of the eye movement in relation to the environment had changed. Rightward movements of the eyes no longer gave the false impression that my view traced a rightward path through the environment: I now used them to look towards the left. Although my experience now appeared surprisingly natural, this did not mean that my visual experience of the location and orientation of objects was now the same as my experience without inverting glasses. One way in which I could contrast the novel experience with the experience without inverting glasses was by considering the eye movements involved in tracing a rightwards path through the scene. But also without considering movement or the felt direction of my eyes, my experience was clearly different from visual experience without inverting glasses. Without head movements, initially experience is transformed by donning inverting glasses in the same way as by a left/right inversion of the environment. After adaptation to inverting glasses, I did not experience a pictorial "flipping back" of the scene. My sudden change of experience was more like a Gestalt switch that led to a different way of experiencing the world. The fact that I did not experience a visual inversion of the environment or a pictorial inversion of experience shows that there remained crucial differences between normal vision and visual experience after adaptation with inverting glasses.

To understand my experience at this point it is useful to consider the new sensorimotor patterns to which I had become accustomed (see Fig. 1). With inverting glasses, an eye movement towards the left traced a path through the environment that could be continued by moving my head to the right. An object that in reality stood on the right side of central vision could thus be brought in central view either by moving my eyes to the left, or by moving my head to the right. Without inverting glasses, of course, an object standing to the right of the focus point can be brought into central vision by moving either my eyes or my head to the right. Suppose I would be drawing on my normal visual skills, acquired during years of looking without inverting glasses. Following a line by moving my eyes to the right would then appear indicative of a trajectory towards the right. If I would be implicitly relying on these normal regularities while wearing inverting glasses, the result would be a different way to experience the same visual scene. It seems that this is exactly what happened when I occasionally fell back to the pre-adaptation-way of seeing the scene.

When first wearing inverting glasses I could correctly judge the direction of objects simply by saying that an object was at the right of the visual field when it visually appeared to be at the left. In that case, I had to deliberately infer the correct direction. During adaptation, non-inferential perceptual judgments became correct again, and my visual system had once again become adapted to the environment. Now, it is undoubtedly true that one can become used to the changed experience; in that sense, experience can become normal again. But as Gibson puts it, adaptation to

inverting glasses can be described as the "veridicalizing" of perception rather than as merely a normalization of perception (Gibson 1964, p. 11). In fact, from a first-person perspective it is more accurate to describe my transformed experiences as the accurate or veridicalized visual experience of spatial location, rather than as the recovery of the pre-experimental normal visual experience.[5] The fact that, even without head movements, veridicalized vision with inverting glasses was not like a pictorial inversion of the experience before veridicalization, testifies to experiential differences between normal visual experience and veridicalized vision with inverting glasses. In other words, I found that an accurate visual experience of location can differ phenomenally from the normal visual experience of location. This vindicates a distinction between the apparent object of perception and the phenomenal character of perceptual experience (e.g., Degenaar 2013).[6]

In short, my experience of visual direction provides two more indications of the limitations of the metaphor of a visual image, in addition to the limitation related to visual stability. First, there is the simple observation that the experience of visual direction cannot be captured in terms of the location within the visual field. Rather than providing a full-blown inversion of the visual world, inverting glasses leave the experience of visual direction partly intact, as the experience of the general direction of the visual field remains relatively undisturbed. Second, the sudden change of experience after adaptation to inverting glasses was like a Gestalt switch experienced when looking at an ambiguous figure, rather than like a pictorial change. I described my experience with inverting glasses in terms of the integration of momentary experiences within the larger flow of visual experience associated with movements of the head and the body. This way we can make sense of the experiential differences associated with the Gestalt switch of perceptual adaptation. We can describe the differences in terms of the different ways in which momentary experiences appear to fit in a larger flow of experience. In accordance with the sensorimotor account of visual experience, this description appeals to the larger patterns of bodily interaction with the environment, rather than to the notion of a visual image. Importantly, this sensorimotor description captures prominent aspects of experience with inverting

[5] See also the report of Dolezal, who writes: "If the question, 'Does anything re-reverse?' means 'Are the new appearances *indistinguishable* by any criterion from the remembered appearances of pre-spectacle days?' then the answer is an unequivocal 'no'." (Dolezal 1982, p. 228). Kohler quotes a subject saying that "the picture remains the same, but it is experienced differently" (Kohler 1964b, p. 155), and he even reports a comparison with a particular multistable picture, Schröder's stair illusion (Kohler 1964a, p. 33). This confirms experiential differences between normal vision and vision after adaptation to inverting glasses.

[6] Note that this goes against a certain type of intentionalism. According to intentionalism, there can be no difference in the phenomenal character of experience without a difference in the intentional content of experience (e.g., Byrne 2001; Tye 1995). My findings indicate that intentionalism is false if it cashes out spatial intentional content in terms of the apparent location of objects. But perhaps the intentionalist may appeal to a different notion of intentional content and provide an account of veridicalized vision with inverting glasses according to which the intentional content of the experience is different after all. A way to save intentionalism may be to postulate eye-movement-related intentional content to make the difference between pre-experimental experience and veridicalized experience with inverting glasses. Importantly however, such a theoretical manoeuvre would not undermine the crucial difference between the apparent environmental object of the experience and the phenomenal character of experience. For an exploration of Gestalt switches in relation to certain forms of intentionalism, see also Macpherson (2006) who discusses (and rejects) a few possibilities for representationalists/intentionalists for explaining experiential differences without pictorial differences.

glasses that are overlooked in a pictorial interpretation.[7] Let us now turn to mental imagery, where the metaphor of a visual image seems particularly strongly entrenched in our thinking.

## Mental imagery

On the 30th day, when I could see objects at their true location, my experience was like a bi-stable percept. Like the experience of the Necker cube, I could see the scene in different ways. I could deliberately imagine what the effect of head movements would have been, had I not worn inverting glasses—for example, I could imagine which parts of the world would then have come into view by turning my head to the right. When I imagined such effects, objects that were on my left visually appeared as if they were on my right. My subsequent findings can best be understood against this background.

By considering the sculptures of birds mentioned above, with beaks pointing to the upper left, I discovered that memory or mental imagery played tricks on me. When I looked at these sculptures for a while through my inverting glasses, and then closed my eyes, I could retain the sight for a few seconds: I could vividly imagine what it would be like to see the objects. Keeping my eyes closed, I then indicated with my hand the direction of their beaks as I experienced them. To my surprise, I consistently pointed in the wrong direction. There was nothing wrong with my bodily feeling of left or right, but somehow my visual memory failed in an unexpected way.

The next morning I repeated the test. Again I pointed in the wrong direction when I based my hand direction on visual memory. But I then kept moving my head, while imagining what the sight of the objects would be like. With eyes closed, I had no trouble to vividly imagine the sight of the scene that I would have encountered if I had kept my eyes open, with my inverting glasses on. When I subsequently indicated the direction of the beaks as I imagined them, the direction of my hand was in accordance with their real direction. I tried the same for other objects, with the same results.

Next, I took the test one step further: I would no longer move my head, but merely imagine how my experience would vary with movements of my head. I found I could retain the proper left/right orientation: by indicating with my hand the direction of objects as visually remembered, I consistently made correct judgments.

Note that, when I still pointed in the wrong direction based on mental imagery, the incorrect direction of my hand was consistent with the pre-experimental relation between eye movement and the spatial position of objects: I had to move my eyes to the upper right to follow the birds' beaks pointing to the left. Thus my findings are consistent with the idea that my memory skills were still drawing on the normal significance of eye movements, rather than on the new significance brought about by wearing inverting glasses.

[7] Of course proponents of the notion of a visual image could respond by insisting that the notion still applies at the subpersonal level. For example, a Gestalt switch may then be viewed as a case in which a hypothetical visual image inside the head remains the same, while a subsequent cognitive operation on this image differs. Whatever the basis for such assertions may be, the point here is that at the level of experience the description in terms of a visual image has serious limitations.

On reflection, this should not be surprising. For the last 30 days of training, I had focused on looking rather than on memorizing, and now I was testing my visual memory or imagery rather than my visual skills. Moreover, I now imagined the statues as I had seen them without moving my head, so that eye movements became particularly relevant. On the assumption that visual imagery is embodied in a way that is closely related to the processes underlying visual experience, we may even have expected the memory failure. After all, imagery in which imagined eye movements in a lower left/upper right direction would trace the direction of the birds' beaks would normally conform with beaks in a lower left/upper right direction, rather than to beaks in a lower right/upper left direction.[8]

My findings show that under influence of real or imagined head movements, mental imagery or short-term visual memory "veridicalized," in the sense that non-inferential judgments based on visual memory now conformed to reality. Imagery has its perceptual counterpart (to a certain extent it is to the subject as if he or she perceives), and above I offered reasons to think of perceptual experience in terms of sensorimotor engagement with the environment. My findings suggest that the relevance of eye movements and head movements is also reflected in mental imagery or visual memory. Thus, it seems that the embodiment of imagery or visual memory is closely akin to—and perhaps overlaps with—the embodiment of perceptual engagement with the environment.

Although visual imagery may initially seem to invite an interpretation in terms of visual images rather than sensorimotor skills, my findings suggest a different reading. In the previous sections I have shown how the notion of a visual image fails to adequately characterize visual experience. It is interesting to note that my findings on the experience of visual direction may carry over to the experience of visual imagery. Indeed, we may make sense of the momentary experiences of visual direction in imagery in terms of the way in which these experiences fall within the larger flow of experience, which involves the (imagined) visual consequences of head movements. Similarly, a sensorimotor description can be applied to imagined visual stability and instability: the imagined visual grasp of the scene (or lack of visual grasp), which cannot be expressed in terms of the possession of a visual image for reasons explained in "Visual stability," can be described as an experience that is as if one is able to track objects (or unable to do so when a lack of visual grasp is imagined).

I have not investigated memory effects during a longer period, but it would be interesting to further test the ways in which visual memory is grounded in perceptual interaction. For example, when a movie is seen on a large screen with inverting glasses with a restricted scope, so that movement of the head plays a serious role in watching the movie, will memory be based in head movements? If so, one would expect that memory of orientation will be more likely to be correct in cases where head movements play a crucial role, compared with cases where only eye movements

[8] I suppose that there is an analogue in imagery for eye movements, which might be called "imagined eye movement." This could be interpreted as shifts of attention or "mental scanning", in which "subjects covertly go through the motions of such scanning" (Thomas 1999). By gently touching your closed eyelids while imagining looking around at a familiar scene, you may be able to ascertain that imagery sometimes comes with overt eye movements as well.

are involved, for the relation between head movements and the field of view remains unaltered by inverting glasses. Further research in these matters may throw further light on the embodiment of visual memory.

## Conclusions

Experience with inverting glasses reveals how eye movements and head movements are key factors in spatial vision. Above I have reported my findings on visual stability, the experience of the visual direction of objects, and visual imagery. I argued that an accurate description of visual experience does not reduce to a description in terms of the possession of a visual image and that a sensorimotor description can capture prominent aspects of experience with inverting glasses. In particular, a sensorimotor description can do justice to the experience of visual stability and instability, to the ambiguities in the experience of spatial direction, and to the Gestalt switch associated with the "veridicalization" of experience with inverting glasses—none of which are captured by descriptions in terms of visual images. I further reported effects of adaptation to inverting glasses on mental imagery, placing imagery in a sensorimotor context. My findings contribute to the development of a sensorimotor approach by specifying which sensorimotor patterns are crucial to describe visual stability and the experience of visual direction, and by extending this description to visual imagery.

We can now get back to the puzzle raised by the literature. Recall that an interpretation of the literature in terms of visual images gives the impression of conflicting findings: while some reports would suggest that vision remains fundamentally "inverted" after adaptation to inverting glasses, others would rather suggest that a "re-inversion" occurs. Above I offered a more fine-grained analysis of my experience with inverting glasses. We can now see how this analysis provides a new interpretation of the findings reported in the literature, and that the seemingly huge differences in experience are an artifact of the pictorial interpretation.

First, my analysis undermines the pictorial interpretation of visual experience. I pointed out that visual stability requires a visual grasp of the scene that goes beyond being exposed to sweeping images: in the case of sweeping images one may still be able to track parts of the image with one's eyes, a sensorimotor capacity that is impaired when one first wears inverting glasses. By appealing to patterns of sensorimotor interaction with the environment, I could also capture aspects of the experience of visual direction that are left out of descriptions in terms of visual images. Before full adaptation to inverting glasses, the experience of visual direction grounded in head movements differs from the experience grounded in eye movements, a consequence of wearing inverting glasses that cannot be analyzed as simply a matter of an inversion of a visual image. While some sensorimotor patterns remain unaltered by inverting glasses (e.g., to look to the right one has to turn one's head to the right), others are systematically altered (e.g., to look to the right one has to turn one's eyes to the left). Inverting glasses introduce a conflict at the very heart of spatial

vision, reflecting these different sensorimotor patterns related to head movements and eye movements.[9]

We can now achieve a new understanding of the differences that remain between normal vision and vision with inverting glasses—differences that can be found for example in Stratton's report (Stratton 1897). As described above, perceptual adaptation to inverting glasses does not cancel out all the differences with normal vision. In static cases, the initial effect of inverting glasses could be described as an inversion within the field of vision. After adaptation to the glasses, there was a clear difference in experience (even in cases without head movements in which I had my head directed straight ahead). This difference was comparable to the different ways in which one may experience bi-stable stimuli such as the Necker cube. The fact that no image inversion was apparent indicates that adaptation to inverting glasses did not fully counteract the change of visual experience brought about by inverting glasses. Thus, adapted vision with inverting glasses remains different from normal vision.

Note that this description avoids an analysis in terms of an inverted visual image. As said before, to describe the initial effect of wearing inverting glasses—the effect of an inversion within the field of vision—we have to recognize the ambiguities within spatial visual experience. It would be a mistake to suppose that visual experience remains fully inverted after adaptation to inverting glasses, for it was never fully inverted in the first place. A description of vision with inverting glasses in terms of visual images also fails to capture the crucial difference in experience evidenced by the Gestalt switch associated with the "veridicalization" of experience—the difference between the initial experience with inverting glasses and adapted vision with inverting glasses. These differences in experience can be described by appealing to the transformed sensorimotor relations with the environment.

While differences remain between normal vision and vision with inverting glasses, we can now also acknowledge that there are ways in which visual phenomenology with inverting glasses becomes normal again, as suggested by the reports of Taylor (1962) and Kohler (1964b). As I described, the visual field became once again integrated in the larger stream of vision; the conflict between the visual consequences of eye movements and head movements resolved. Veridical perception of the position of objects was thereby re-acquired. In other words, descriptions of visual experience in terms of the apparent location of objects became once again as they were in the case of normal experience. Importantly however, this does not imply that there is no difference between normal experience and the adapted veridicalized experience with inverting glasses. That there are such differences is clearly evidenced by the different ways in which one may see the scene after reaching perceptual adaptation (the Gestalt switches between different ways to experience the environment). Even if after

[9] The occurrence of inconsistent perception has been noted before. See for example Dolezal, who points out that wearing inverting glasses results in "contradictory verbal descriptions" of the position, orientation, or direction of movement of objects (Dolezal 1982, p. 227). Still, the significance of this finding seems to be frequently overlooked, and Dolezal instead connects it to the altered experience of oneself, writing that "The facts of *any* spectacle study are critically misrepresented by the assumption that *only* the places and objects of the external world are optically displaced, reversed, or inverted relative to an observer to whom we attach the device, whereas the observer perceives himself–herself as remaining unchanged in relation to this transformed environment. (…) the facts are that at first the observer suffers massive perceptual confusion regarding the direction of the location—*relative to the self*—of places, objects, events (…)" (Dolezal 1982, p. 227, second and third emphasis added).

adaptation to inverting glasses, the object-oriented judgments become correct again (as was also found by Taylor and Kohler), my findings indicate that phenomenologically the experiences remain different from normal vision. This vindicates a distinction between regarding perception on the one hand from an object-oriented or perceptual knowledge-oriented stance, and on the other hand from a perceiver-oriented or mode of engagement-oriented phenomenal stance (e.g., Degenaar 2013).

Note that in one respect my findings remain somewhat different from the findings as reported by Taylor and Kohler. It seems that two ways of seeing the scene could be *simultaneously* grasped by Taylor's subject, who saw a chair both in its actual place and on the opposite side (Taylor 1962, p. 202). The same goes for Kohler's subject, who apparently had the experience of seeing two lights when only one was presented (Kohler 1964b, p. 161). In my case, the different ways of seeing were rivals: I experienced the scene either as part of a larger flow of vision as it used to be without inverting glasses, or as fitting within the newly acquired patterns of interaction with the environment but never both at the same time.

In short, I suggest that, when an accurate experience of the position of objects is restored, the resulting experience differs from normal visual experience in a way that can neither be described as the full re-inversion of experience nor as the remaining of inverted vision. The Gestalt switch experienced after adaptation to inverting glasses shows that visual experience changes without a visual image "flipping back." A sensorimotor description of vision with inverting glasses can articulate what the Gestalt switch consists in, by appealing to the larger patterns of interaction in which the experiences appear to fit. Such a sensorimotor description can do justice to findings that appear conflicting when interpreted in terms of visual images.

I also found effects of adaptation to inverting glasses on visual memory or mental imagery. At first, visual memory or imagery of objects appeared to be grounded in eye movements, according to the significance they have in the absence of inverting glasses. By deliberately giving a larger role to (real or imagined) movements of the head, short-term visual memory veridicalized too, and the scene was once again imagined to be as it was actually experienced. We may appeal to apparent sensorimotor patterns to describe the resulting spatial visual imagery. For example, to imagine something as pointing to the left is to experience it as conforming to particular sensorimotor dependencies: it is as if one may look where the object points by turning one's head to the left. The demonstrated role of real or imagined movements in visual imagery, and the fact that imagery can adapt under influence of wearing inverting glasses, provide strong indications that imagery is grounded in sensorimotor engagement with the environment. Rather than falling back on descriptions in terms of images, visual imagery may best be understood in terms of the way in which the experience fits within an imaginary flow of visual engagement.

Let me conclude this undertaking in experimental phenomenology by recalling Stratton's (1897) report, where he pointed out that the inverted position of the retinal image is not essential to upright vision, for the whole system of visual objects can never by itself be either inverted or upright. To this we might now add that there is more to visual phenomenology than the harmony between touch and sight. As long as we remain sensitive to eye movements and head movements, we can differentiate between normal upright vision, and upright vision with inverting glasses. I suggest that this is not just because we can compare vision with tactile or motor perceptions,

but because our bodily engagement, involving eye movements and head movements, is what we must reflect on when we reflect on visual phenomenology.

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