Visual Adaptation to a Remapped Spectrum

Lessons for Enactive Theories of Color Perception and Constancy, the Effect of Color on Aesthetic Judgments, and the Memory Color Effect

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Many forms of visual adaptation have been studied, including spatial displacements (Heuer & Hegele 2008), spatial inversions and rotations (Heuer & Rapp 2011), removing or enhancing various colors in the visual spectrum (Belmore & Shevell 2011; Kohler 1963), and even luminance inversion (Anstis 1992). But there have been no studies that have assessed adaptation to an inverted spectrum, or more generally color rotation. We present the results of an adaptation protocol on two subjects who wore LCD goggles that were driven by a video camera, but such that the visual scene presented to subjects was color-rotated by 120°, so that blue objects appeared green, green objects appeared red, and red objects appeared blue (with non-primary colors being analogously remapped). One subject wore the apparatus intermittently for several hours per day for a week. The second subject wore the apparatus continually for six days, meaning that all his visual input for those six days was color rotated. Several experiments were run to assess the kinds and degrees of adaptation, including Stroop (1935), the memory color effect (Hansen et al. 2006), and aesthetic judgments of food and people. Several additional phenomena were assessed and noticed, especially with respect to color constancy and phenomenal adaptation. The results were that color constancy initially was not present when colors were rotated, but both subjects adapted so that color constancy returned. However, there was no evidence of phenomenal color adaptation. Tomatoes continued to look blue, subjects did not adapt so that they started to look red again. We found no reliable Stroop result. But there was an adaptation to the memory color effect. Also, interesting differences were revealed in the way color affects aesthetic judgments of food versus people, and differences in adaptation to those effects.

Keywords
Aesthetic judgments | Color constancy | Color phenomenology | Color rotation | Enactive perception | Inverted spectrum | Inverted spectrum thought experiment | Memory color effect | Phenomenal adaptation | Semantic adaptation | Stroop | Visual adaptation

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1 Introduction

The idea of a subject whose visual experience is color inverted has been a philosophical mainstay at least since Locke (1975), and has fuelled a great deal of philosophical work on the nature of perception up to the present day. In psychology, testing the extent to which subjects' visual systems can adapt to alterations in visual input has likewise been a fruitful mainstay for over a century (for current research and references see Heuer & Hegele 2008; Heuer & Rapp 2011; Belmore & Shevell 2011). Despite these two facts, adaptation to an inverted spectrum has never been studied. Given that there is adaptation to a wide range of distortions to visual input, including spatial manipulations and spectral filtering, we speculated that it was conceivable that there might be adaptation, in some form or other, to color rotation. That is, if visual input was reworked such that tomatoes appeared blue, would subjects over time adapt so that tomatoes regained their normal (red) phenomenal appearance? And even if such a shocking result did not occur, might there nevertheless be adaptation to other color-relevant phenomena, such as color constancy, aesthetic judgments, or the memory-color effect?

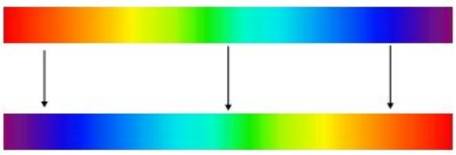


Figure 1: An inverted spectrum. The familiar red-to-violet spectrum laid out from left to right (top) compared to an inverted violet-to-red spectrum from left to right (bottom). Note that the central colors map to themselves or very similar colors.

We tested this as follows. First, rather than an inverted spectrum, we employed a *rotated spectrum*. An inverted spectrum is one in which one takes the usual red-to-violet spectrum and just reverses it to get a mapping from colors to colors. Red would map to violet, orange to blue, violet to red, and so on (see figure 1).

For two reasons we chose to systematically alter color input not with an inverted spectrum, but with color rotation (see figure 2). In a 120° degree rotation, greens become reds, reds become blues, and blues become greens (see figure 3).

One reason to employ a rotation rather than an inversion is that in a rotation, all colors map to different colors, whereas in a spectral inversion, the middle of the spectrum maps to itself, and so not all colors differ. Also, with a 120° rotation, primary colors map to primary colors, and this was convenient for testing purposes. For instance, we wanted to test semantic adaptation via a Stroop task, and Stroop is difficult to test if one is dealing with non-canonical colors (since subjects pause to think of what seems to be the best name for the color: "... um, periwinkle?"). It was important that the text was colored in a primary color during baseline testing (before subjects' vision was color-altered), and that it continued to be presented in a primary color during testing while colors were altered.

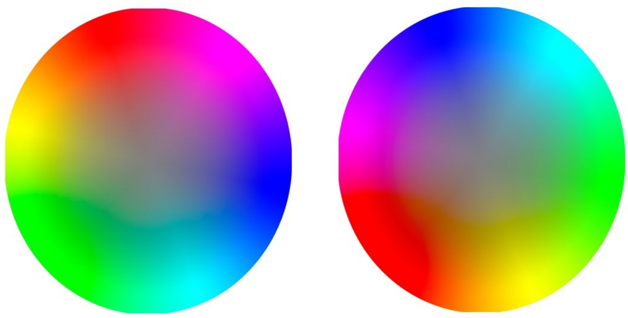


Figure 2: Color rotation. If colors on the left disk are mapped to colors that are 1/3 of a clockwise rotation (120º), then green (lower left) maps on to red (slightly left of the top); red maps to blue (middle right); and so forth. The disk on the right is a 120º color-rotated version of the disk on the left.

The rotation was implemented in the following way. A small video camera was mounted on a bike helmet, as were a pair of LCD goggles (see figure 4). The sides of the goggles were sealed against the wearer's face so that there was no peripheral visual input; subjects could only see what was displayed on the LCDs. The video camera output was run to a laptop computer, which ran software that color-rotated the video feed and pushed the result to the LCD goggles. The subject would wear the bike helmet and carry a bag that held the laptop and battery packs for the laptop, camera, and goggles. In what follows we will refer to this as the *rotation gear*, or simply the *gear*. Moreover, we will use the expression *under rotation* to refer to the condition of having one's visual input color-rotated by the gear. In addition to rotating the spectrum (the intentional effect), the gear also eliminated binocular disparity since there was only one camera (which projected the same image to both eyes), and also impaired peripheral vision, since the camera's field of view was less than normal vision. As a result, while most normal activities were possible (if cumbersome), some, such as driving a motor vehicle, were not possible.

Figure 3: A typical outdoor scene color-rotated by 120º. (http://www.open-mind.net/videomaterials/grush-color-video)

There were only two subjects, and both were investigators in this project (and authors of this paper). This was for practical reasons. First, we anticipated that UCSD Internal Review Board would be reluctant to grant human subjects approval, based both on the length and significant inconvenience of the protocol and also because this particular protocol had never been attempted before, and so, for example, there was no precedent concerning whether such a regimen might cause long-term damage to participants' color vision. And even if approval were obtained, we anticipated that finding volunteers for such a protocol would be difficult, and, even if we did find them, the small grant we were operating with did not give us the resources to appropriately compensate them. Employing two of the investigators as subjects solved these problems. Because investigators were aware of the protocol and risks, and were intimately familiar with the relevant equipment and potential problems and so in a position to more accurately assess conditions under which the protocol should be aborted, some of the concerns were eased, and approval was eventually granted. Moreover, investigators were willing to put themselves through the arduous protocol.

Subject 1 (RG) wore the gear intermittently, in several multi-hour sessions per day for a week. Two reasons for an initial intermittent protocol were, first, that it would allow us to trouble-shoot the equipment—if it had to be shut down for a few hours for tinkering this would not interfere with the protocol, and we wanted to ensure that everything was functioning smoothly before subject JK's continuous protocol began. And, second, we wanted to compare the results of a subject who wore the gear intermittently with the results of one who wore it continually. Subject JK wore the gear continually for six straight days, meaning that he had no unrotated visual input for that entire period. He slept with a blindfold and showered with closed eyes in the dark, but otherwise wore the gear at all times.

Figure 4: The camera and goggles used.

Our high-level goals were to assess phenomenal and semantic adaptation. Phenomenal adaptation would manifest as a return to normalcy such that under rotation tomatoes would start to look red again, the sky would appear blue, and so forth (this is discussed in more detail later on). It might also manifest as a gaining of color constancy under rotation. These would be parallel to adaptation to spatial inversion in which, after adaptation objects begin to look right-side-up again. We assessed this in several ways. One was the memory-color effect. A second was aesthetic judgments. A final method was subjective report: subject JK kept a hard-copy journal in which he wrote observations, and RG had a digital voice recorder that he used for similar purposes. There were also audio recordings made during the testing periods, as well as when JK finally removed the rotation-gear.

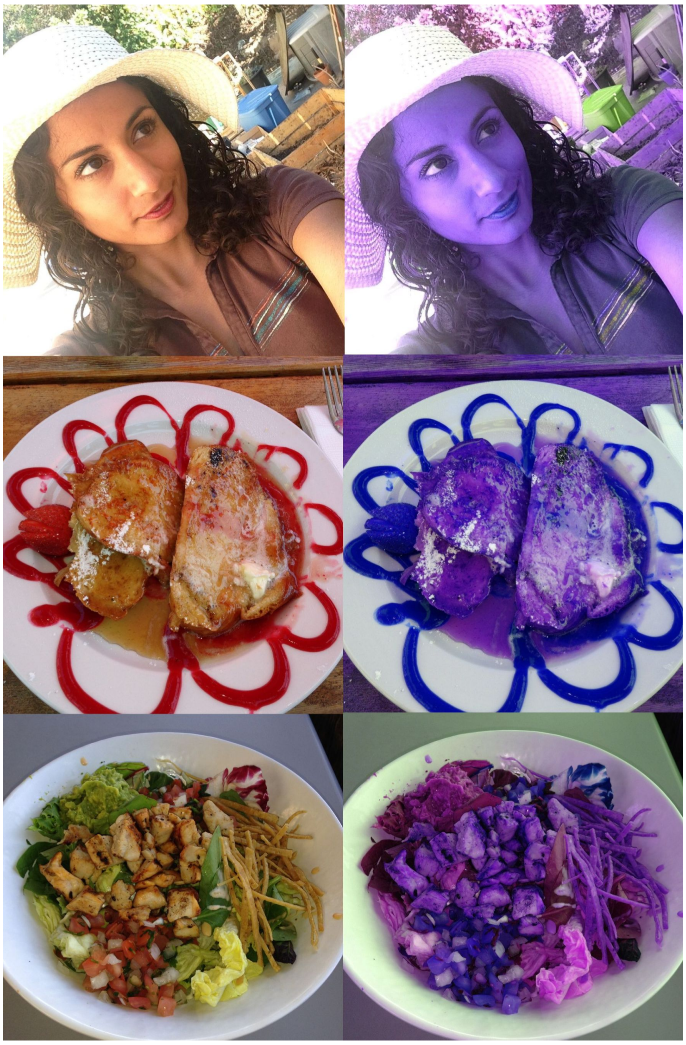


Figure 5: Images of people and food, in normal color, and with a 120º color rotation, for purposes of illustration only—none of these was in the stimuli set used in the experiment. The food items are French toast with maple syrup and strawberry confit (middle row), and chicken salad with guacamole (bottom).

Semantic adaptation would manifest as a remapping of color terms to their "correct" referents. So, for example, when first putting on the gear, if a subject were asked to pick up the "blue block," they would pick up a block that was in fact red. Would subjects semantically adapt such that the word "red" was immediately semantically connected to the red block, despite the fact that the block was presented as blue through the rotation gear? This was assessed via subjective report and Stroop. In the following sections we discuss each investigated phenomenon, the results we found, and their implications.

For all experiments there were four times at which trials were run: i) *pre-rotation*, in which trials were run after the subject initially put on the gear but the colors were not yet rotated; ii) *early rotation*, wearing the gear and first color-rotating visual input; iii) *late rotation*, at the end of the time during which the subject was wearing the gear and had time to adapt; and iv) *post-rotation*, while the subject was still wearing the gear, but colors were not rotated. The reason for running trials (i) and (iv) while wearing the gear without rotating the colors, rather than just through normal vision without the gear, was to control for effects possibly due only to the fact that visual input was going through a camera and LCD goggles. For some experiments there were additional times at which the trials were run, as will be explained below.

A final note on methodology. A number of factors distinguish the current study from an appropriately run and controlled psychological experiment. The small n and the fact that both subjects were also investigators in the study are perhaps the two most significant differences. These limitations were forced by a variety of factors, including the unusual degree of hardship faced by subjects, our relatively small budget, and the fact that this protocol had never been tried before. Because of these limitations, the experiments and results we report here are intended to be taken only as *preliminary* results—as something like a pilot study. Even so, the results, we believe, are quite interesting and suggestive.

2 Color, color constancy, and enactive vision

According to proponents of enactive perception, perceptual experience amounts to relevant behavioral skills (O'Regan & Noë 2001; Noë 2004, this collection).

> To be a perceiver is to understand, implicitly, the effects of movement on sensory stimulation [...]. An object looms larger in the visual field as we approach it, and its profile deforms as we move about it. A sound grows louder as we move nearer to its source. Movements of the hand over the surface of an object give rise to shifting sensations. As perceivers we are masters of the sort of sensory dependence [...]. We spontaneously crane our necks, peer, squint, reach for our glasses, or draw near to get a better look (or better handle, sniff, lick, or listen to what interests us). The central claim of what I call the enactive approach is that our ability to perceive not only depends on, but is constituted by, our possession of this sort of sensorimotor knowledge. (Noë 2004, pp. 1–2)

The enactive approach correctly predicts that there will be adaptation to certain kinds of spatial distortion to visual input (Noë 2004). The idea is that if perception is a matter of learning sensorimotor contingencies, then though these contingencies can be disrupted via altering the spatial features of the input, the new contingencies can be learned (they are just a different set of contingencies, after all) and when this happens, perceptual input will seem normal again.

Noë (2004) boldly claims that not just spatial features, but even color phenomenology might be explained on enactive principles.

> Our ability to perceive [a] wall's color depends on our implicit understanding of the ways its apparent color varies as color-critical conditions vary. At ground, our grasp of these dependencies is a kind of sensorimotor knowledge. We can distinguish two different kinds of sensorimotor dependencies [...]. Crucially, the perceptual experience of color depends on the perceiver's knowledge of both kinds of sensorimotor patterns.
>
> Movement-dependent sensorimotor contingencies are patterns of dependence between sensory stimulation, on the one hand, and movements of the body, on the other [...].
>
> [O]bject-dependent [...] sensorimotor contingencies [...] are patterns of dependence between sensory stimulation and the object's movement, or the object's changing relation to its environment. (Noë 2004, pp. 129–130)

Accordingly, our protocol speaks as directly to the enactive account of color as inverting prisms speak to an enactive account of vision's spatiality. Notice that the technological apparatus of color rotation comes into play *after* both sorts of patterns have manifested (with the exception of eye movements, which happen after the rotation is effected, though this fact does not change any of the contingency patterns). What this means is this: suppose that there is a particular way that a red surface changes its reflectance properties both as we move around it (movement-dependent), and also as it changes relevantly with respect to the environment (object-dependent). Call this pattern of changes Pattern R. And suppose that the same is true for a blue surface, meaning that it has a different, but characteristic pattern of changes we can call Pattern B. To get a specific example, let's suppose that the red surface gets brighter when it gets angled upwards, but the blue surface does not (the details of these patterns don't matter for purposes of illustration, all that matters is that there are such patterns, and that they differ for different colors). Whatever the patterns R and B are, they occur whether anyone is wearing rotation gear or not. But after the rotation gear is involved the surface that is behaving according to Pattern R will be presented to the subject with stimulation from the blue part of the spectrum, and the surface that is behaving according to Pattern B will be presented with stimulation from the green part of the spectrum. For instance, the subject will see the *apparently blue* surface getting brighter as it is angled upwards, which is Pattern R, because the apparently blue surface is actually red, and hence behaves according to Pattern R.

So the question is: after experience with red surfaces, which behave according to objective patterns appropriate to red surfaces (Pattern R), but are presented through the goggles with blue parts of the spectrum, will these surfaces start to look red again? This is clearly the prediction that is made by the enactive theory of color, since to appear red just is to behave according to Pattern R on this theory, and the surfaces that are being presented with light from the blue parts of the spectrum are behaving according to Pattern R. The enactive theory makes this prediction for both color constancy and color phenomenology. We will discuss color constancy first.

We did not test color constancy in any controlled way, but the subjective reports are quite unmistakable. Subject RG noticed that upon first wearing the rotation gear color constancy went "out the window." To take one example, in normal conditions RG's office during the day is brightly lit enough that turning on the fluorescent light makes no noticeable difference to the appearance of anything in the office. But when he turned the lights on after first donning the gear, everything had an immediate significant change of hue (though not brightness). He spent several minutes flipping the light on and off in amazement. Another example is that he also noticed that when holding a colored wooden block, the surfaces changed their apparent color quite noticeably as he moved it and rotated it, as if the surfaces were actively altering their color like a chameleon. This was also a source of prolonged amusement. However, after a few days the effect disappeared. Turning the office light on had little noticeable effect on the color of anything in his office, and the surfaces of objects resumed their usual boring constancy as illumination conditions or angles altered.

Subject JK reported the same thing: an initial period in which the apparent colors of objects shifted widely with changes in illumination conditions or viewing angles, followed after a day or two with the restoration of color constancy such that those same changes had no effect on apparent color.

There was one difference, though, between RG and JK. While RG's perceptual system gained the capacity for color constancy under rotation, he never lost color constancy in normal conditions. After the first few days of intermittently wearing the gear, objects had stable apparent colors whether he wore the gear or not. Though of course the colors that were stable were different in the two conditions. JK (who wore the gear continuously for six days) also gained color constancy under rotation, but lost it for normal conditions, as was apparent at the end of his trial when he removed the gear. Indeed, almost immediately after he removed the gear and was seeing things without rotation for the first time in six days, he spent several minutes flipping a light switch on and off and marvelling as the apparent color of everything in the room changed at his command (while no one else in the room noticed anything). So while RG's visual system became, so to speak, bi-constant, because he switched back and forth between rotated and non-rotated visual input, JK's visual system, because it was exclusively rotated for six days, gained color constancy under rotation, but temporarily lost normal color constancy. Normal constancy returned for JK within a few hours after he stopped wearing the gear.

These results are precisely what the enactive theory of color constancy would predict. Initially the kinds of patterns of color-relevant change exhibited by objects in the environment was different from what the visual system had come to expect, both in terms of changes in environmental conditions generally (e.g., switching on a fluorescent light), and movement specific changes (e.g., walking around them or rotating them in hand). The sensorimotor contingencies changed, and as a result color constancy was disrupted. But after a period of time during which these new dependencies were, presumably, learned, color constancy was restored.

A more convincing protocol would be one in which there were control subjects whose visual input was rotated, but who were not active in their color environment. Such a protocol would be difficult to implement. Wearing rotating equipment for six days is quite difficult. If you were then to disconnect visual input from overt behavior on top of that, this would become extremely burdensome for test subjects. This could be done either by having the video camera not moving at all, or moving randomly; or by recording the video from a rotated subject as they are actively exploring their environment, and simply play that video back to control subjects, so that their visual input would not change at all as a consequence of their own actions. But even though there was no control of this sort in our protocol, it is safe to say that the proponent of an enactive theory of color constancy should be encouraged by this result.

But what about color adaptation? Did red surfaces start to look red again? The results here are less encouraging for the enactive theorist. With one interesting and suggestive observation to be discussed shortly, we found nothing that suggested color adaptation. As assessed by subjective report, stop signs continued to appear blue, the sky green, and broccoli red throughout for both subjects.

Though this is not the result that the enactive theorist would hope for, it isn't entirely conclusive. First, it may have been the case that a protocol of longer than six days would have resulted in phenomenal adaptation. Six days may simply not have been long enough to learn the new relevant sensorimotor contingencies. This is certainly possible. But it should be noted that all other sorts of visual adaptation (to spatial inversions, spectral filtering etc.), including our own result with adaptation to color constancy, occurred in less than six days.

Second, the gear does in fact introduce a lot of artefacts besides just the change in presented colors. Artefacts are introduced by the digitization of the image and its presentation through LCD goggles. So proponents of the enactive theory of color needn't jump off a building just yet. They may maintain that because of these artefacts, the process of relearning the needed sensorimotor contingencies was somehow short-circuited.

But there are a couple of considerations that suggest that the result is not so easily dismissed. First, whatever artefacts the gear did introduce were not such as to make any difference to normal color vision. If one wears the gear without color-rotation, things appear to be in their normal colors. This seems to suggest that whatever patterns of change account for our ability to see normal things in their normal colors, they are not significantly compromised by whatever artefacts the gear introduced. This would seem to remove some of the motivation from the suggestion that adaptation did not occur because of artefacts introduced by the gear. Second, the gear clearly maintained enough information about patterns of color change that adaptation to color constancy occurred fairly quickly. Again, this suggests that much or all of whatever is important in patterns of change relevant to color perception is preserved by the gear. If it was not, adaptation to color constancy should not have occurred. The one thing not preserved by the rotation gear was the sensorimotor-*independent* feature of which retinal cells were stimulated when various surfaces were in view. And that one feature seems to be the best candidate for the determinant of apparent color, given that everything else changed but apparent color did not.

We mentioned above that there was an interesting pair of events that, while not quite amounting to phenomenal adaptation, are at least very suggestive. On two occasions late into his six-day period of wearing the gear, JK went into a sudden panic because he thought that the rotation equipment was malfunctioning and no longer rotating his visual input. Both times, as he reports it, he suddenly had the impression that everything was looking normal. This caused panic because if there was a glitch causing the equipment to no longer rotate his visual input, then the experimental protocol would be compromised, and the value of his days of sacrifice in the name of science and philosophy would have been significantly diminished.

However, the equipment was not malfunctioning on either occasion, a fact of which JK quickly convinced himself both times by explicitly reflecting on the colors that objects, specifically his hands, appeared to have: "OK, my hand looks purplish, and purple is what it should like under rotation, so the equipment is still working correctly."

Prima facie there seems to be a clear difference between i) a tomato looking "normal" because it now appears phenomenally to be red; and ii) a tomato looking "normal" because though it appears blue, one is now used to tomatoes appearing blue, that is, blue no longer appears unusual. JK's situation was a case of (ii), but the lack of a sense of novelty of strangeness made him briefly fear that he was in a (i) situation. He described it as a cessation of a "this is weird" signal.

Even though (i) and (ii) seem to be quite different, the phenomenon is suggestive. It indicates that there is definitely a stage in which the subject requires explicit reflection to discern (i) from (ii). This might lead one to speculate that this stage might signal an early stage of genuine color adaptation (we will discuss this further in the final section).

But it could also be an initial stage of a very different possibility, one discussed by Noë himself:

> [...] the strongest [inverted spectrum] arguments ask us to consider the possibility in the first person. At stage 1 I am inverted. At stage 2, I get used to the inversion. I realize things now look color-inverted compared to the way they used to look, and I use this knowledge to guide my correct use of words. I get really good at acting normal. At stage 3, I suffer amnesia and forget that things ever looked different. The point of this thought experiment is that it suggests a reason to believe that things are now different with me with respect to my color experience, even though I am now unable to report those differences. (2004, p. 94)

While JK never suffered from amnesia, his two episodes suggest that it is possible to at least go some distance down precisely this path.

3 The memory-color effect

If subjects are given control over the hue of an image and asked to adjust it until it appears grey scale there is an interesting effect. If the image is of an object with a salient prototypical color (such as bananas, which are saliently and prototypically yellow), subjects will judge that it is grey scale when in fact the hue is slightly in the direction opposite to that of the standard color. So, for example, an image of a banana will be judged to be grey scale when it is in fact just slightly periwinkle. This is the memory-color effect (Hansen et al. 2006). One possible explanation of this effect is that when the image actually is grey scale, subjects' top-down expectations about the usual color make it appear (in some way or another) to be slightly tinted in that hue. So when the image of the banana is actually completely grey scale subjects judge it to be slightly yellow. The actual color of the image must be slightly in the direction opposite yellow (periwinkle) in order to cancel this top-down effect and make the image appear grey. This is the memory-color effect.

We expected that after a period of wearing the gear this effect would diminish or even reverse. The reasoning was that if the rotated experience either just disrupted the association of the objects with their prototypical color, or even established a different prototypical color, the effect would be compromised.

Stimuli used in our trials were images of a banana, tomatoes, broccoli, a fire engine, a school bus, a stop sign, and a Starbucks logo. We wanted examples of natural objects as well as artefacts with strong color associations. We also used squares and circles, which have no obvious prototypical color, as controls. The hue of the initial image presentation was random, and subjects were to adjust the hue until the image appeared completely grey scale.

There were technical issues with RG that prevented his data from being usable. But subject JK's results were in fact what we expected. Pre-rotation, JK's results were normal. He judged the stimuli to be grey when in fact they were, on average, 3.5% saturated in the direction of the opponent color. JK was quite consistent with this except for one stimulus condition, broccoli, which he actually exhibited the opposite of the expected pattern. He judged it to be grey when it was about 1% saturated in its normal color. The effect was robust, and we have no idea why. We suspect that it was some sort of artefact connected to that stimulus being presented through the rotation gear, but we don't know for sure.

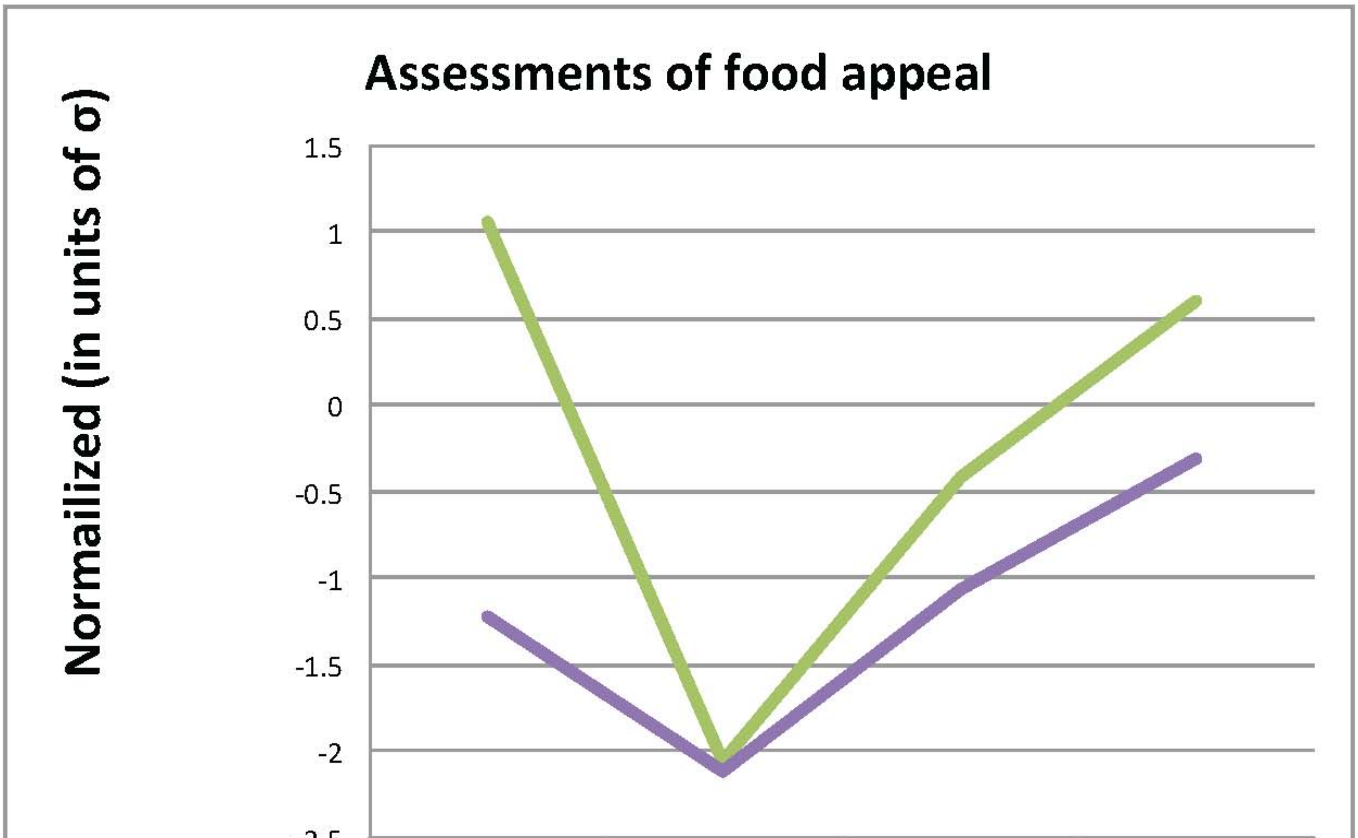
Post-adaptation JK's assessments were, on average, about 0.5% saturation, again in the direction of the opponent color. Meaning that he still exhibited the effect, but its magnitude was lessened. This could mean one of two things: i) the rotation protocol disrupted the usual associations of colors and objects, and so all stimuli ended up being treated by his perceptual system just as controls, that is, as objects with no salient associated color; and ii) JK partially adapted to objects' new prototypical colors. Unfortunately the result we got, in which assessments were on average very close to grey, is consistent with both. The alteration was consistent with both a movement towards grey and a movement towards the canonical color, since both are in the same direction from a spot opposite the canonical color. But one consideration that speaks in favor of (ii) is that the broccoli stimuli, post-adaptation, did not move towards grey, but in fact were judged to be grey when they were even more green than in the pre-rotation trial. That is, the broccoli stimuli judgments moved not in the direction of grey, but in the direction of canonical color, and by about the same amount as the other stimuli moved in that direction: 2.5%.

Our result in the memory-color effect and the two occasions in which JK panicked are consistent. Both effects would seem to result from a re-aligning of the salient prototypical color of objects that have a salient prototypical color. The adaptation of the memory-color effect suggests that the experience of being color-rotated lessened the extent to which top-down effects associated certain objects with their actual prototypical colors, and perhaps even started associating them with new, different prototypical colors. And the lack of the "this is weird" signal when viewing his purple hand also suggests that the old prototypical look of his hand was being supplanted with a new prototypical look. And it also suggests not just that the old prototypical color association was being lessened, but that a new one was emerging. What failed to look weird was his *purple* hand—not just a hand in any non-flesh color, but in *purple*. We did not test this, but it seems quite unlikely that had his hand suddenly looked bright red he would have similarly experienced a loss of the "this is weird" signal. This is speculative, but it at least suggests, consistently with the broccoli effect discussed above, that the result we saw with the memory-color effect was not just a loosening of the old associations, but the emergence of new ones.

Moreover, the adaptation of the memory-color effect appears to have been *general*. The items we used for testing in the memory color effect fell into two groups: first, there were those items, such as Starbucks logos and bananas, which were such that items of that type were observed at least sometimes during the period of rotation; and second there were others, such as fire trucks and baby chicks, which were not observed by the subject under rotation. If what was being altered by rotated experience was just the specific associations of colors with experienced objects, then we should have found different results for these two groups of objects. Bananas and Starbucks logos would be subject to adaptation with respect to the memory-color effect, and fire trucks and baby chicks would not. But this is not what we found. We found the memory-color effect was impacted for *all* tested objects, even those that had not been seen during rotation.

This suggests that the effect was general, meaning that the adaptation was manifested not as an alteration in some part of the perceptual system concerning its expectations about what bananas or other specific objects look like. Rather, the alteration appears to have concerned expectation about what *yellow things* generally look like. To put it in dangerously loose and anthropomorphic terms, some part of the system started cranking up the periwinkle knob when objects known to be yellow, like baby chicks, were seen. If this is indeed a *memory* effect (psychologist do, for some reason, call it the *memory*-color effect), then it suggests that some part of the system knew that baby chicks were supposed to be yellow, but was beginning to misremember what yellow was like.

Table 1: Assessments of food appeal. The graphs show the average scores for both subjects. For each subject, before testing each subject scored all images on a scale of 1–10, 10 being the most appealing. These scores were used to establish a normalization for each subject so that all scores could be re-expressed in terms of σ. They were also used to divide the dishes into high-rated and low-rated groups for each subject. Each subject then re-assessed each dish at four times during the experiment: pre-rotation, early-rotation, late-rotation, and post-rotation (see text for explanation). As can be seen, upon color rotation all dishes plummeted in their perceived appeal to a level below the score the unappealing dishes had before rotation. But after adaptation (late rotation) the low-rated dishes regained all of their appeal, and the high-rated ones regained a moderate amount.



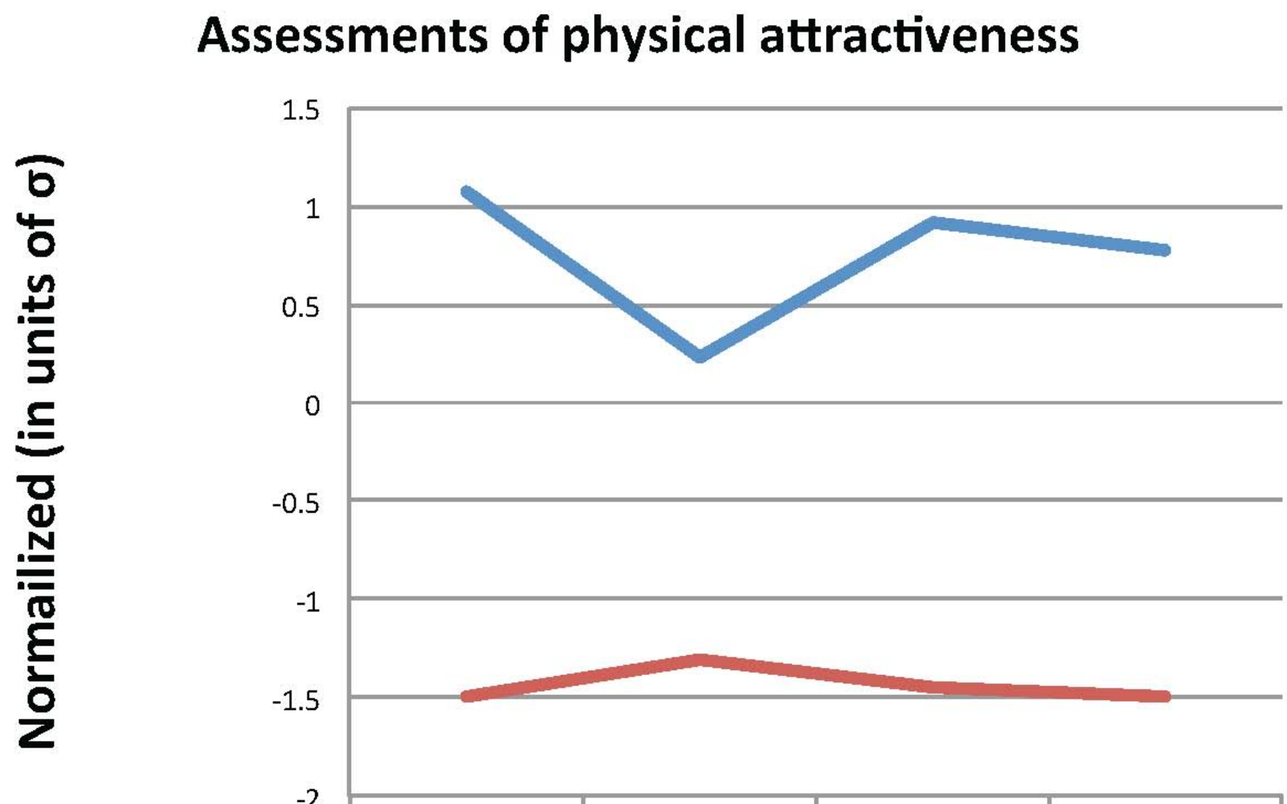
	Pre-rotation	Early-Rotation	Late-Rotation	Post-Rotation
Food (High-rated)	1.06	-2.06	-0.41	0.6
Food (Low-rated)	-1.23	-2.12	-1.06	-0.31

Recall where we left off in the last section. There was a suggestion to the effect that for a subject who underwent an inverted spectrum procedure, a cessation of the “this is weird” signal, together with a loss of memory of how things used to look might result in that subject’s inability to report differences between their current inverted experience and their prior non-inverted experience. Such a subject would of course verbally report that their phenomenology had adapted (or, if they were more reflective, they might also admit the possibility that their phenomenology was still inverted, but that their memory was failing to make this fact apparent to them). To indulge in some wild speculation, the general nature of the adaptation to the memory-color experiment suggests that something along these lines might possibly happen if there was a longer adaptation period. We will return to this in the final section.

4 Aesthetic judgments

Color plays a large role in a variety of aesthetic judgments. Red broccoli doesn’t look terribly appealing as a food item, and Hollywood main-

Table 2: Assessments of physical attractiveness of people. The graphs show the average scores for both subjects. For each subject, before testing each subject scored all images on a scale of 1–10, 10 being the most attractive. These scores were used to establish a normalization for each subject so that all scores could be re-expressed in terms of σ. They were also used to divide the images into high-rated and low-rated groups for each subject. Each subject then re-assessed each image at four times during the experiment: pre-rotation, early-rotation, late-rotation, and post-rotation (see text for explanation). As can be seen, color rotation had much less effect on ratings of physical attractiveness of people than it did on the appeal of food. The low-rated group was essentially unchanged throughout the protocol. The high-rated group experienced a relatively small drop during early-rotation, but regained nearly all of it by late rotation.



	Pre-rotation	Early-Rotation	Late-Rotation	Post-Rotation
People (High-rated)	1.07	0.23	0.92	0.77
People (Low-rated)	-1.49	-1.3	-1.44	-1.5

tains that gentlemen prefer blondes. But to what extent are these judgments malleable with experience? Might the red broccoli start to look more appetizing if one has enough experience eating it? To assess these questions we ran two aesthetic judgment experiments. In one, we measured how appealing different dishes looked, and in another we measured judgments of physical attractiveness of people (figure 5). For the first we used images from a large cook-book with a wide variety of dishes. For the second, since both subjects were heterosexual males, we used pictures of adult women taken from the internet. In both cases we separated the stimuli into high-rated and low-rated groups so that we could assess whether color rotation had a differential effect. And in both cases we ran four trials: an unrotated baseline trial of judgments before beginning the rotation period; an early-rotation trial immediately upon wearing the rotation gear; a late-rotation trial at the end of the adaptation period; and finally a post-rotation trial normal color vision was restored. Subjects scored all stimuli with a 1–10 numerical rating. We used the normal vision early-rotation ratings of each subject both to sort stimuli into subject-specific high-rated and low-rated groups, and to establish a normalization (average and standard deviation) so that we could translate all ratings provided by each subject in terms of σ, meaning that 0 was average, 1 was one standard deviation above average, –1 was one standard deviation below average, and so forth.

The results can be summarized quickly (see table 1). For dishes in the appealing group, their appeal ratings immediately dropped significantly from pre-rotation to early-rotation. The drop was, on average, 3σ, from an average of 1.06σ to an average of –2.06σ! Some notes from JK's diary speak to the effect of color rotation on food appeal:

> Spinach looks a glossy, poisonous red (it's the texture and the color that look really nasty together, I think).
>
> I genuinely lost my appetite at the sight of four enormous bowls of glossy red salad, pale pink cheese, blue kidney beans, deep blue beets, bright red peas, etc. […]
>
> I've noticed that I don't anticipate food at all the way I normally do. Normally during the day I think about food, think about making food, think about eating food, and when I get a full plate of tasty looking food in front of me, I'm a very happy person. Now there's a real disconnect between the way food tastes and the way it looks, and I don't honestly find myself craving anything during the day. I get hungry, yes, but a full plate of food in front of me looks intensely neutral on the desirability scale.

At the end of the adaptation period, those high-rated dishes had regained half of their appeal, being judged on average about –0.41σ. Both RG and JK followed this pattern. Interestingly though, in the post-rotation rating, RG's ratings returned to within .35σ of baseline for the appealing dishes (to .71σ compared to an initial average rating of 1.06σ), while JK's ratings were lower, returning only to within 0.61σ of baseline, from 1.09σ to 0.48σ. But this is still a very significant absolute gain. On average, both ratings returned to 0.60σ post-rotation. Again, from JK's diary after his return to normal vision and going to a salad bar:

> The various greens were really intensely "green," the carrots looked like they were going to leap out of the buffet line. The onions (red onions) were the only vegetable that didn't surprise me with its vividness. I was horribly hungry; eating was immensely pleasurable. You have no idea how nice it is for food to look and taste right.

For the less-appealing group of dishes the ratings also dropped immediately from pre-rotation to early-rotation, on average by .89σ, from –1.23σ to –2.12σ. This group of dishes recovered to –1.06σ in late-rotation, just slightly above their pre-rotation ratings. In post-rotation this group of dishes rose to above their baseline ratings, to –0.31σ, nearly a full standard deviation above their pre-rotation baseline!

Interestingly, the overall pattern was that while the high-rated dishes started at 2σ, and low-rated dishes started at –1σ, they all dropped to the same –2σ immediately upon early-rotation. The color rotation just made everything, dishes that normally looked appealing as well as those that did not, look very unappealing. After adaptation at late-rotation, the lower-rated dishes recovered all of their perceived appeal (low though it was), and the higher-rated dishes recovered half. But it is worth remarking that the appealing dishes had a larger absolute gain after adaptation, suggesting that experience with appealing and unappealing food did have an effect on how each subject judged the appeal of foods based on color. Unappealing dishes returned to their normal level of unappeal, and the appealing dishes made significant gains towards looking as appealing as they had before.

As for the physical attractiveness assessments, the effect of color rotation was much less pronounced than it was in the case of food. We dubbed this the Star Trek effect (in honor of

Captain Kirk's romantic liaisons with green alien women): attractive people are still pretty attractive whether their skin is blue, or green, or any other color.

The results are summarized in table 2. As in the case of food, we did an initial norming trial, and then separated stimuli into high-scoring and low-scoring groups. And we tested at the same four times: pre-rotation, early-rotation, late-rotation, and post-rotation. For the low-scoring stimuli, there was almost no difference across the four trials. The average rating in this group started at –1.49σ pre-rotation, and then actually (slightly) improved during early-rotation to –1.30σ. Late-rotation ratings fell to –1.44, and then post-rotation ratings were at –1.50. Basically, color rotation had no pronounced effect on this group, either before or after the adaptation period.

For the high-scoring stimuli the pattern was more interesting. Pre-rotation average was 1.07σ, which dropped to 0.23σ immediately at early-rotation. While this is indeed a drop, it is a *much* smaller drop than the corresponding condition with food, in which high-rated dishes dropped 3.00σ. High-rated people ratings dropped only about ¼ as much as high-rated food ratings upon rotation. Late-rotation the high-scoring people had nearly completely rebounded to 0.92σ, only 0.15σ less than their pre-rotation scores. Post-rotation the ratings dropped slightly to 0.77σ, meaning that the people were actually judged to be less attractive in their normal color, than they were when color-rotated, though the degree of drop was small.

The difference we found between food and people is consistent with studies involving less extreme color manipulation. It is well known that color has a very large effect on the appeal of food (Delwiche 2004; Zampini et al. 2007; Shankar et al. 2010). Existing studies of food-color effects typically involve less extreme color manipulations than we studied here, but the results are similar. With people, though skin color does have an effect on perceived attractiveness, structural features (e.g., facial bone structure, symmetry, body proportions) seem to be more significant (Barber 1995; Dixson et al. 2007).

5 Semantic adaptation

We were keen to investigate the extent to which there would be semantic adaptation. When a normal fluent English speaker hears "red" as part of a sentence, a host of cognitive and behavioral states and processes are invoked that are keyed to a certain phenomenal appearance. If I ask you to "hand me the red block" you can immediately and without overt reflection grasp the correct block, even if it is surrounded by other, differently colored blocks. To what extent would color-rotated subjects show semantic adaptation? Would a point be reached at which the sentence "hand me the red block" just as fluently resulted in the grasp of the block that was in fact red, but presented as blue?

To help facilitate semantic adaptation both subjects spent a good deal of time each day performing tasks requiring engagement with color vocabulary. The most relevant of which was the building game, in which subjects were given written or verbal descriptions for building constructions from colored blocks. The constructions required blocks of specific colors to be placed in specific locations and orientations. Instructions were given in terms of the blocks' actual color. Success required that subjects select the correct blocks even though the color terms used mismatched their visual input.

Our main method of testing adaptation in a detailed way was Stroop (1935). For technical reasons we have data only for JK (RG's trail exposed a problem with the interaction between the goggles and the computer display presenting the stimuli, which rendered those data unusable but did allow us to fix the issue so that we could collect valid data from JK). In one standard Stroop set-up, subjects are shown color words presented in colored text, the text either spelling out a color name, or being a neutral series of asterisks, such as ****. For example, subjects might see the word RED in blue text. The task is to name, as quickly as possible, the color of the text while ignoring the color named by the word. When presented with the word RED in blue text, the subject is to say "blue" as quickly as possible.

The standard result is that there is significant interference. Subjects are fastest and most accurate when the color of the text and the color word match, as in the word BLUE in blue text. When there is a mismatch, they are slower and commit more errors, especially errors in which the subject replies with the color word named by the text, and not the color of the text. Our hypothesis was this: with colors rotated by 120° but before a period of adaptation, subjects would show the same pattern as normal subjects in that they would have interference when the color named by the text mismatched the rotated color of the text. So for example the word RED in red text (which would be presented as blue through the goggles) would result in interference, but the word RED in green text (which would be presented as red) would not. But after wearing the gear for a period of time there would be some degree of semantic adaptation. This would manifest in two ways. First, there should be facilitation, or at least diminished interference, when the color named is the same as the actual color of the text, even though it is presented in a different color. And second, there should now be interference, or less facilitation, when the color named is the same as the color in which the word is presented, because that color would be different to the color the word actually is.

The results were that we found no significant effect in either direction. This was disappointing, but it is consistent with the subjective reports of both RG and JK. They both remarked that it quickly became easy to do the appropriate translation and, for instance, grab the green block when one was instructed to "grab the green block" despite its being presented as red through the goggles. But even near the end of their adaptation periods, it still felt like it was an active (though fast and easy) translation, and not a pre-reflective semantic connection between "green" and the actually green objects.

6 Discussion

All of the experimental results reported here should be treated as pilot study results. Our n was very small, either 1 or 2 depending on the experiment, and investigators were themselves experimental subjects. Both of these are significant limitations. Nevertheless we're confident that any follow-up studies, with larger n, with more subjects who are not investigators, and perhaps with better equipment than we had available (for example, a camera with higher resolution), will yield results consistent with ours. We hope that any group that chooses to follow up will have an easier time than we did. To that end, we can report that post experiment both subjects' vision returned to normal, including color discrimination (which we assessed a few days post gear), and so perhaps with verification in hand that the protocol is safe, it will be a little easier for others to get approval for use of human subjects.

The experiment as we have described it was designed to assess, among other things, phenomenal adaptation. We've acted so far as though what this means is obvious. But we're now in a position to see that it isn't obvious at all. For anyone who believes in qualia (and Dennett 1988 is right when he says that most people do, philosophers or scientists, whether they realize it or admit it or not), then the idea would be straightforward. Phenomenal adaptation would occur when, for instance, tomatoes start causing red qualia again, even if the subject is wearing the rotation gear. There are alternatives to the qualia theory. The enactive approach offers one: the idea would be that phenomenal adaptation is nothing but *enactive adaptation*, that is, learning new sets of sensorimotor (and related) contingencies. Our results, especially the lack of any straight-forward phenomenal adaptation, though far from decisive put at least a little pressure on the enactive view, however. Another approach (e.g., Dennett 1988) would be to first cash phenomenology out in terms of inner discriminatory states that are tied to various reactive potentials. Described in this broad way, the enactive approach would be a very special case. The reactive potentials would include behavioural dispositions and possibilities, and even predictive possibilities, but also aesthetic reactions, emotional reactions, cognitive reactions, and so forth. As Dennett puts it, the mistake made by the believer in qualia is the mistaken belief that

> [...] we can isolate the qualia from everything else that is going on—at least in principle or for the sake of argument. What counts as the way the juice tastes to x can be distinguished, one supposes, from what is a mere accompaniment, contributory cause, or byproduct of this "central" way. One dimly imagines taking such cases and stripping them down gradually to the essentials, leaving their common residuum, the way things look, sound, feel, taste, smell to various individuals at various times, independently of how those individuals are stimulated or non-perceptually affected, and independently of how they are subsequently disposed to behave or believe. (1988)

On this view, JK (and to a lesser extent RG) may have been part way down the path to the only thing that would legitimately count as phenomenal adaptation, namely, changes in the way that some inner discriminatory ability is evoked and what its various consequences are. As we found, aesthetic judgments had started to adapt, and even the memory-color effect had begun to adapt in a way that speculatively may have been a reflection of alterations in what canonical colors were supposed to look like. Moreover, JK was losing his "this is weird" signals. And though we did not find evidence of semantic adaptation, it would be quite surprising, given humans' ability to learn new languages and dialects, if after a more extended period of time semantic adaptation did not occur.

Whatever the details, for purposes of this experiment, we don't feel compelled to take a detailed stand on any of this. We would have been satisfied with subjective report of phenomenal adaptation, and then left it to further philosophical and even psychological investigation to unpack what this could mean. Nevertheless, the adaptation to color constancy and the memory-color effect, as well as the loss of the "this is weird" signal, are all suggestive results that we hope will help move debate in the relevant fields forward.

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What Can Sensorimotor Enactivism Learn from Studies on Phenomenal Adaptation in Atypical Perceptual Conditions?

A Commentary on Rick Grush and Colleagues

Aleksandra Mroczko-Wąsowicz

Grush et al. present a pilot study on visual adaptation to a remapped color spectrum. Their preliminary results, being far from conclusive, only partially support the hypothesis that there might exist a form of adaptation to color rotation and color constancy. Proving such flexibility in color vision would substantiate the investigators' attempt to localize their research outcomes in the context of philosophical theories of enactive perception. In spite of some limitations, the study exhibits a worthy and novel approach to the old question of color inverted experience, intended to provide an interdisciplinary account that is both empirically sensitive and philosophically potent. For the progress of the current investigation it would be constructive not only to conduct empirical follow-up studies, but also to conceptually refine the notion of "phenomenal adaptation", which is the central phenomenon studied here.

Based upon a distinction between phenomenal conservatism that accepts only perceptual phenomenology with sensory contents and phenomenal liberalism that acknowledges higher-level contents of perception and cognitive phenomenology, I differentiate between adaptation of the sensory sort and adaptation in the cognitive aspects of experience.

This distinction is used to highlight two different ways of understanding the notion of "phenomenal adaptation", exhibited by the target article and this commentary. Grush et al. seem to suggest that phenomenal and (non-phenomenal) semantic adaptation are different forms of a more general phenomenon of adaptation. However, they do not give any explicit example of the genus of adaptation of which these types are a species. I contend, in turn, that there is no need to produce such subclasses of the notion; semantic adaptation involving higher-level non-sensory states may also be understood as phenomenal. This follows from phenomenal liberalism. I argue that what is being processed in the course of phenomenal adaptation is phenomenal character understood in an expansive way that includes high-level contents. The claim may have an important effect on related empirical work. As a result, enactive sensorimotor adaptation does not have to be seen as adaptation of the sensory sort, but as adaptation in the cognitive aspects of experience, such as altered expectations, or beliefs about or sensitivity to kinds of objects encountered in perceptual experience. This phenomenally liberal reading would provide an appropriately more capacious notion than the adaptation of the sort offered by Grush et al.

Finally, I claim that the lessons for enactive theories of color perception may be expanded beyond the implications of the color rotation study. This is demonstrated by turning to confirmatory and challenging cases of atypical perceptual conditions and color modifications, such as synesthetic color experiences.

Keywords
Adaptation | Color inversion | Color vision | Constancy | Enactivism | Inverted spectrum | Perceptual experience | Phenomenal character | Sensorimotor | Sensorimotor contingency | Synesthesia

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1 Introduction

Philosophical thought experiments focusing on different kinds of visual spectrum manipulation and color inversion were initiated with John Locke's hypothetical case of strawberries producing visual experiences of cucumbers (Locke 1689/1979). They still influence not only philosophical theories of color perception and color qualia inversion (e.g., Shoemaker 1982; Clark 1985; Levine 1988; Block 1990; Casati 1990; Broackes 1992; Hardin 1993; Tye 1993, 2000; Nida-Ruemelin 1993, 1996; Byrne & Hilbert 1997; Hurley 1998; Hilbert & Kalderon 2000; Cohen 2001; Myin 2001; McLaughlin 2003; Noë 2005; Churchland 2005; Macpherson 2005; Cohen & Matthen 2010; Burge 2010; O'Regan 2011), but also psychological research on the various ways in which our conscious experience can be modified and adapted to changes in visual input, such as space or luminance inversion (Heuer & Rapp 2011; Anstis 1992), or removing or enhancing colors (Belmore & Shevell 2011). However, a systematic interdisciplinary study on adaptation to an inverted or rotated color spectrum has been lacking until now.

The target article aims to lay the foundation for this, by presenting an experimental pilot study, along with some preliminary results and a brief discussion of its theoretical implications. Like many other pilot studies, it faces some limitations. These are: the small number of subjects tested; experimenters acting as test persons; and a complete lack of control conditions in the experimental protocol. The investigators are aware of these constraints and provide convincing reasons for the choices and strategy, e.g., their use of a novel, unpredictable, long-lasting, and inconvenient test protocol. Despite some difficulties relating to both empirical and conceptual aspects, the study demonstrates an original, interesting, and most importantly interdisciplinary approach to the topic of color perception and constancy, making an effort to combine psychological research with philosophical enactive theories.

The main objective of this commentary is to discuss what the sensorimotor account of perceptual consciousness could learn from investigations into phenomenal adaptation in atypical visual conditions such us color rotated spectrum and synesthesia. In the first section, after pinpointing the conceptual and methodological difficulties involved in defining and testing phenomenal adaptation in Grush et al.'s study, I shall deepen our understanding of phenomenal adaptation and analyze various possible readings of this phenomenon. Such readings depend on different interpretations of the contents that are admissible to perceptual consciousness (cf. Hawley & Macpherson 2011). In the second section, the relationship between the color rotation study and the enactive account of color vision is examined in order to demonstrate what consequences the sensorimotor theory may expect from results that confirm it in some respects, but not others. Finally, in the last two sections, I claim that the lessons for enactive theories of color perception may be expanded beyond the implications of the color rotation study. This is verified by looking at confirmatory and challenging cases provided by atypical perceptual conditions and color modifications such as synesthetic color experiences.

2 Phenomenal adaption

The notion "adaptation", being central to the target article, while used comparably to analogous work on perceptual effects of systematic alteration of sensory input, does not obviously correspond to the unambiguous physiological notion of adaptation, i.e., a decrease over time in the responsiveness of sensory receptors to changed, constantly applied environmental conditions (e.g., Held 1965; Noguchi et al. 2004; Smithson 2005). Distinguishing semantic adaptation (a remapping of color terms and building immediate semantic connections to their proper object referents) from phenomenal adaption, Grush et al. focus on phenomenal aspects of regaining both stimulus constancy and original color arrangement in spite of changes in input. Given that adaptation to numerous alterations in visual input has already been reported in various studies (Kohler 1962, 1963; Anstis 1992; Heuer & Hegele 2008), Grush and colleagues also hypothesize the possibility of some form of adaptation to a version of the color-inverted spectrum. They designed a series of experiments to assess phenomenal adaptation of visual experience under color rotation by 120°, which leads to "tomatoes [...] causing red qualia again, even if the subject is wearing the rotation gear" (Grush et al. this collection). The definition of "phenomenal adaptation" in the target article is "a return to normalcy" and "a gaining of color constancy under rotation". Phenomenal adaptation then, can be understood as the regaining of phenomenal qualities of the pre-rotated color experience while using the rotation equipment for some time, such that experienced colors are stable, constant, and non-rotated, i.e., just like in normal color vision under standard conditions.

But there are reasons to think that adaptation is not necessarily a phenomenally-conscious phenomenon. Such an assumption is supported by research with blindsight patients exhibiting, in their unconscious perception, spectral wavelength sensitivity and several other features of color vision adaptation (Stoerig & Cowey 1989, 1991). In addition, adaptation should not be confused with habituation, which is an attentional phenomenon over which subjects reveal some conscious control (Webster 2012). This could help to explain some of the difficulties Grush et al. encountered when trying to prove the occurrence of phenomenal adaptation under color rotation—which are described below.

2.1 Conceptual problems — Defining phenomenal adaptation

For most of the target paper, Grush et al. treat "phenomenal adaptation" as if it has a single, obvious, and straightforward meaning. Only at the end do they briefly hint at different readings of such adaptation depending on the understanding of the notions "phenomenal" or "qualia". That is, their investigation is driven by certain implicit assumption of phenomenal qualities. However, these terms are quite controversial in philosophy and one may wonder what actually is examined in the study.

Philosophers denying the existence of phenomenal qualities or qualia (e.g., Churchland 1985, 1989; Tye 1995, 2000; Dennett 1988) may understand them in a specific and narrow sense, either as consciously-accessible properties of non-physical mind-dependent phenomenal objects, mental images called sense data (Lewis 1929; Robinson 1994), or intrinsic non-representational properties (Block 1990; Peacocke 1983), or non-physical, ineffable properties of experiences given to their subjects incorrigibly (Dennett 1988, 1991). Nonetheless, qualia may be endorsed in a broader sense, namely as phenomenal character. This use of the term generally refers to introspectively accessible qualitative aspects of one's mental life, and it is hard to deny that these exist. Phenomenal character of an experience is "what it is like" for a subject to undergo the experience (Shoemaker 1994, 2001; Chalmers 1996; Nagel 1974). While engaging in introspection and focusing attention on the phenomenal character of experience, one is aware of and gets access to certain phenomenal qualities that make up the overall phenomenal character of the experience.

Since there is no single definition of the term "phenomenal qualities" or "qualia", there might be also more than one reading of the notion of "phenomenal adaptation". Depending on the particular understanding of phenomenality and the sort of mental states that can have phenomenal qualities or enter phenomenal consciousness, there seem to be different ways of interpreting the phenomenon of adaptation and thus the possibility of different kinds of adaptation. A related matter discussed in the philosophy of perception—between those supporting phenomenal liberalism and those who propose phenomenal conservatism (expansive and restrictive conceptions of the domain of phenomenal consciousness)—is whether there are high-level properties in the content of perception and whether cognitive states have a distinctive and proprietary phenomenology (Bayne 2009; Prinz 2012).

Phenomenal conservatism (e.g., Tye 1995, 2000; Carruthers 2005; Braddon-Mitchell & Jackson 2007; Nelkin 1989), proposing austere perceptual phenomenology, i.e., that the contents of perception are exclusively of the sensory sort, promotes sensory adaptation. Phenomenal adaptation, understood as sensory adaptation, has been described in the literature as adaptation to various distortions and systematic alterations of sensory input employing single or multiple modalities. For example, subjects wearing prismatic goggles or lenses inverting a visual scene in terms of color and spatial arrangement can adapt in the course of time to these new settings and become able to act normally, because they develop new visuo-tactile contingencies that allow them to get around and efficiently see and reach for objects (Held 1965). Importantly, such an adaptation directly affects perceptual experience and cannot be explained by correcting judgments. But this may not be the whole story about phenomenal adaptation, since phenomenal character does not have to be limited to sensory experiences, although traditionally it is said to be. In line with phenomenal liberalism, contents of perception may contain high-level properties such as kind properties (e.g., the property of being a tiger; recognizing that something belongs to a certain kind—seeing a tree as a pine tree; Siegel 2006; Bayne 2009), but also causal (the property of one thing's causing another; Strawson 1985; Siegel 2006; Butterfill 2009), and generic properties (the property of being nonspecific; Block 2008; Grush 2007). These properties are abstract, generalized, and cognitive in their nature, yet they can enter into phenomenal contents. Consequently, a liberal conception, allowing cognitive states to possess phenomenal qualities, and phenomenal character to be ascribed to conceptual contents, endorses cognitive phenomenology and thus would opt for phenomenal adaptation in the cognitive aspects of experience.

The debate surrounding cognitive phenomenology involves many different versions and strengths of the claim that the domain of phenomenology extends beyond the sensory (Strawson 1994; Siewert 1998; Pitt 2004; Bayne & Montague 2011; Horgan & Tienson 2002; Kriegel 2002, 2007). Irrespective of its particular varieties, such a view raises alternative interpretations of Grush et al.'s results. It suggests that phenomenal adaptation may be present not only in sensory but also in cognitive aspects of experience. Both perceptual and cognitive states determine how we experience the world and adapt to changes in our surroundings, because they both exhibit their own phenomenal characters—something it is like to be in such a state for the subject (Chalmers 1996, p. 10; Strawson 1994; Montague & Bayne 2011).

Moreover, conceptual contents seem able to modify the phenomenal character of perceptual states; they can cognitively penetrate our perception (Raftopoulos 2005; Macpherson 2012; Siegel 2012). An interdisciplinary approach to the cognitive penetrability of perception assumes that there are various ways in which conscious perception can be affected by cognition—i.e., by thoughts, beliefs, desires, judgments, intentions, moods, emotions, expectations, knowledge, previous experiences, and memories (Frith & Dolan 1997; Bar 2003; McCauley & Henrich 2006; McCauley & Henrich 2006; Raftopoulos 2009; Vuilleumier & Driver 2007; Stokes 2012; Deroy 2013; Wu 2013; Vetter & Newen 2014; Briscoe 2014; Nanay 2014; Lupyan 2015). In other words, higher cognitive states not only have causal influence on the contents of perception, they are also explanatorily relevant in accounting for the processing of perceptual systems. It has been shown that semantic contents and categories play a critical role in perception, even in early sensory processing (cf. Mroczko et al. 2009; Mroczko-Wąsowicz & Nikolić 2013). This may be exemplified in the connection between language and color vision. For example, languages with a larger number of generic color terms such as Russian have an impact on color perception (Winawer et al. 2007).

Such an integrative cogno-sensory approach, combining high-level cognitive and low-level sensory aspects, is also manifested in recent theories of concepts relating the possession of concepts to perceptual adaptation in various ways (Machery 2009; Prinz 2010; Noë this collection). For instance, being sensitive and showing a discriminative response to certain kinds of objects or combinations of features corresponds to having concepts for the related kinds of objects (Machery 2009; Deroy 2013, 2014). According to the ability-based account of conceptuality, one can reveal skillful understanding of concepts in a perceptual, practical, or emotional way, meaning that the possession of concepts is a condition that informs and is informed by our able engagement with things (Noë 2012, this collection; cf. Wittgenstein 1953). This indicates a close interdependence between conceptuality and sensorimotor processing.

Consequently, phenomenal adaptation, in light of the enactive theory, would mean enactive adaptation and learning a new set of skills in the form of new sensorimotor contingencies and related dependencies, such as behavioral dispositions, predictive possibilities, and cognitive, aesthetic, and emotional reactions. Enactive adaptation would entail an application of sensorimotor skills to conceptual understanding, and as such it could be seen as adaptation in the cognitive aspects of experience with altered expectations or beliefs about or sensitivity to kinds of objects encountered in perceptual experience. This phenomenally liberal reading would provide an appropriately more capacious notion than the adaptation of the pure sensory sort offered by Grush et al.

To sum up, departing from a distinction between phenomenal conservatism that accepts perceptual phenomenology with solely sensory contents and phenomenal liberalism that acknowledges higher-level contents of perception and cognitive phenomenology (Bayne 2009; Montague & Bayne 2011), I differentiate between adaptation of the purely sensory sort and adaptation in the cognitive aspects of experience. The distinction is used to show the contrast in understandings of the notion of "phenomenal adaptation" between the target article and this commentary. Grush et al. seem to suggest that phenomenal and (non-phenomenal) semantic adaptation are different forms of a more general phenomenon of adaptation. However, they do not give any explicit example of the genus of adaptation of which these later are a species. I contend, in turn, that there is no need to produce such subclasses of the notion; semantic adaptation involving higher-level non-sensory states may also be understood as phenomenal. Thus, the reading of adaptation I put forward pertains jointly to the phenomenal and semantic aspects of regaining of stimulus constancy; it assumes a recovery of prototypical color-object associations both in phenomenal experience and in semantic reference in spite of changes in input. This follows from phenomenal liberalism.

The proposed view is that being processed in the headway of phenomenal adaptation is phenomenal character, understood in an expansive liberal way that includes high-level contents. Therefore phenomenal adaptation is considered to be the adjustment of cognitive aspects of experience.

2.2 Methodological problems

Dissociating semantic from phenomenal adaptation is problematic. This is because they are interconnected. It is hard to think about the occurrence of semantic adaptation without phenomenal adaptation taking place and vice versa – semantic adaptation is methodologically necessary for detecting phenomenal adaptation. This presumed correlation might be the reason why, when faced with difficulties finding phenomenal adaptation to a color-rotated scene, the investigators could not confirm any reliable Stroop results for semantic adaptation. In addition, it should be noted that Stroop-type tasks contain two components of competition—semantic and perceptual (Stroop 1935; Nikolić et al. 2007; Mroczko et al. 2009)—and as such they exhibit limitations in differentiating between semantic and perceptual aspects of the phenomena tested.

To assess the occurrence of phenomenal color adaptation under rotation, that is, the process of the normal phenomenal appearance of objects returning, Grush et al. used the memory color effect (Hansen et al. 2006), aesthetic judgments of food and people, and subjective reports from their test persons.

It has often been assumed that subjective introspective reports are a generally reliable mode of first-person access to one's current conscious states or processes (Descartes 1984; Locke 1689/1979; Hume 1978; Brentano 1973; Husserl 1982; Chalmers 2003; Gertler 2001; Horgan et al. 2006; Horgan & Kriegel 2007; Varela 1996; Rees & Frith 2007; Hurlburt &

Schwitzgebel 2007; Hohwy 2011). However, this assumption is also problematic. Arguments for introspective scepticism or even criticism of introspective methodology pose genuine threats to the trustworthiness of this approach (see Bayne this collection, for a discussion of such views). Because of this ambivalence one needs to be careful when using subjective reports as a source of or support for the results presented.

Certain doubts about whether subjective reports are trustworthy enough come from the fact that introspection delivers solely first-person, unverifiable, private data, and thus it is unscientific and often fallible (Dennett 1991; cf. Zmigrod & Hommel 2011). In addition, subjects tested are often uncertain or disagree about what the introspective access actually provides (Bayne & Spener 2010; see also Bayne this collection) and have difficulty describing their own conscious experiences (Schwitzgebel 2008). Nonetheless, this is not to deny that they have *some* first-person knowledge of phenomenal consciousness.

The specific reasons one may have for doubting the findings in the context of Grush et al.'s study are related to the fact that investigators were also the test subjects. We should avoid involving persons who know the hypothesis when conducting the experiments, who in this case tested and evaluated themselves at the same time. Knowing the research question and the expected or desired results may bias any study.

3 Implications of the color rotation study for sensorimotor enactivism

Grush et al.'s work could be extended to manifest a broader range of philosophical implications than those they have mentioned; but, as the authors state at the end of their article, this has been left for future philosophical and psychological investigation. Referring to a general theoretical framework of perception such as the enactive approach, Grush and colleagues apply the lessons of their study to sensorimotor enactivism of perception without considering other options such as ecological and active perception approaches as potential targets (Gibson 1979; Ballard 1991; Mossio & Taraborelli 2008; Taraborelli & Mossio 2008). However, since their hypothesis focuses on the nature of perception based on couplings between sensory stimulation and motor activity, it appears justified to focus on the sensorimotor version of the enactive account, which emphasizes an active exploration of the environment determining in this way the content and modality of conscious experience (O'Regan & Noë 2001; Noë 2005).

Sensorimotor theory has been supported by research on sensory substitution (Proulx & Störig 2006) and adaptation in haptic perception, as observed in mirror therapy for phantom limb pain and in the rubber hand illusion (Ramachandran & Rogers-Ramachandran 1996; Botvinick & Cohen 1998). Most relevantly, supporting evidence for the sensorimotor theory of color perception was found in a study on adaptation to half-split colored goggles (left-field blue/right-field yellow), which introduced an artificial contingency between eye movements and color changes (Bompas & O'Regan 2006b; cf. Kohler 1962). These results have left the possibility of similar sensorimotor adaptation to any arbitrarily-chosen colors open. According to the account of enactive vision, sensorimotor principles are fully capable of explaining adaptation to alterations in spatial or color-relevant features of input (Noë 2005). The adaptation can be achieved by resuming constancy through learning a new set of sensorimotor contingencies, i.e., patterns of dependence between sensory stimulation and movements, corresponding to new features of the input. Understanding these dependencies provides the required sensorimotor knowledge that enables perceptual experience.

The experimental protocol of Grush et al.'s study directly refers to an enactive account of color (O'Regan & Noë 2001; Noë 2005; Bompas & O'Regan 2006a, 2006b). The authors' hypothesis regarding color constancy and phenomenal color adaptation under color rotation is compatible with predictions made by sensorimotor enactivism; the induced adaptation to a remapped spectrum was supposed to imitate a naturally-occurring process of learning sensorimotor contingencies. The results obtained in this pilot study, although not entirely usable and interpretable, may yet provide food for thought to enactive theory, since they offer some interesting insights into supportive evidence and the difficulties that the theory needs to integrate and deal with.

3.1 An enactivist explanation of the results

Subjective reports concerning adaptation to color constancy, understood as achieving stability of color experience irrespective of visual conditions, confirm what the enactive theory would expect. This means that when switching between standard visual conditions and color rotation, and at the same time being active in the color environment through altering color-critical conditions such as illumination, viewing angles, or movements, the test persons exhibited temporary disruption of color constancy leading to an immediate change of perceived hues. This is allegedly due to the change of sensorimotor contingencies involved in this experience.

However, when a new set of sensorimotor regularities becomes established, color constancy is resumed, so that the subjects gain the capacity for color constancy under rotation and then come back to normal color constancy when having non-rotated visual input, i.e., the colors that are stable are different in the two conditions. Hence, after a period of time for learning new dependencies, color constancy is restored and the mentioned modifications of visual conditions, such as lighting, have no effect on the phenomenal character of color experience.

An interesting observation and an important point for further deliberation on the development of phenomenal color adaptation is delivered in the subjective report of one of the test subjects, who at the end of his six-day color rotation period suddenly begun to be confused about whether his visual input was still rotated or not, because everything appeared normal. Since he ceased to feel a sense of novelty and strangeness, he was not sure if he was in a situation of (1) normal color vision, or rather (2) adaptation to color constancy under rotation—at least until he explicitly reflected on the colors of the surrounding objects. Although he was evidently in state (2), thus experiencing stability of rotated colors, one may suppose that his confusion about which colors were 'normal' in which condition might also indicate the time in which subjects could begin to develop an ability amounting to (3) phenomenal color adaptation under rotation with colors akin to genuine colors in situation (1). Speculations envisioning the occurrence of this adaptation after a longer period than the duration of the current test do not seem completely unjustified. What would be needed here are further studies that not only cover a longer time frame of color rotation, but also focus on searching for a characteristic marker signaling when, within a very smooth transition between (2) and (3), phenomenal adaptation under rotation (stage(3)) actually begins. This would be similar to "the feeling of novelty/strangeness"-marker within the transition between (1) and (2), signaling color rotation. The lack of this marker and the occurrence of the feeling of normality would indicate that color constancy under rotation has arisen.

The memory color effect was used by Grush et al. as a method of assessment for phenomenal color adaptation under rotation. It is an effect of processing colors of objects with typical colors that affects the experience of pairings of colors and shapes (Hansen & Gegenfurtner 2006; Hansen et al. 2006). The authors explain the effect by top-down influences of expectations. But it may also be explained by, for example, cognitive penetration of color experience by beliefs (Macpherson 2012) or sensory adaptation through exposure manifesting itself by responding differently to various kinds of objects or co-occurring features (e.g., arrangements of objects' shapes and their typical colors; Deroy 2013, 2014). All these descriptions express some aspect of the phenomenal liberalism discussed earlier, and as such they seem more or less equally plausible for supporting the proposed reading of phenomenal color adaptation under rotation as adaptation in the cognitive aspects of experience. In standard visual conditions, the memory color effect may suggest that expectations or beliefs about a proper color for a certain kind of objects exert top-down influence on the actual color processing of these objects, their shapes, etc. Thus, the lessened magnitude of the memory color effect under color rotation, as found in the study, shows that the associations of objects with their prototypical colors become weaker and may even get replaced by other associations with new prototypical colors.

This outcome is interestingly combined by Grush et al. with the aforementioned confusion stage (between (1) and (2)) acquired at the end of the color rotation period, when the subject stops having the feeling of novelty and therefore confuses his rotated color experiences with the normalcy felt when perceiving in standard visual conditions. Both of these results imply not only a decreasing strength of the old prototypical color associations, but also the emergence of new associations. Such an emergent set of dependencies is clearly compatible with enactive predictions. The adaptation that took place due to color rotation and that has been demonstrated by the memory color effect appears to be general. This means it is not just a matter of specific associations of colors with particular objects seen during rotation. The adaptation refers to the perceptual system as a whole and its expectations, beliefs, or sensitivity, contributing to a discriminative response to kinds of objects in general. For example, the adaptation might manifest itself as the regaining of a grasp of the way things are colored, as altered cognitive states (cognitive aspects of experience) about what red things generally look like or what red is like.

3.2 Problems with a definitive confirmation of enactivist ideas

Obviously the study protocol would have been more plausible if color constancy had been tested in a controlled way with a relevant objective method and not only confirmed by first-person reports. For example, brain imaging techniques would be suitable for detecting temporary changes in perceptual states. Also, comparing the effect with a proper control group, matching the test group for gender, age, and color-related experience (e.g., education, profession), would certainly increase the strength of the findings, providing more evidence for sensorimotor adaptation to color constancy. Because transformations in qualitative experience may be explained in terms of a dynamic model of interdependence between sensory inputs and embodied activity (Hurley & Noë 2003), phenomenal differences between color experiences can be accounted for by different actions. Therefore to exclude the sensorial interpretation, the control group would not be actively exploring their color environment, would not change the rotated visual input through their own actions, and thus according to the enactive theory would not develop new sensorimotor dependencies allowing stable color perception.

For genuine phenomenal color adaptation different results were observed, i.e., the regaining of non-rotated color constancy while using the rotation equipment was not successfully established—subjective reports and objective assessments made with the memory color effect and aesthetic judgments of color-rotated food and people have shown that subjects only started to adapt in late-rotation, at the end of the possible adaptation period. Difficulties in robustly confirming phenomenal color adaptation under rotation are certainly not encouraging news for the enactive view of color. They could even be interpreted as a falsification of this theory. However, according to the investigators, this is still not decisive, and they speculate that the reason for this unfavorable outcome could be the lack of time allowed for relearning the relevant sensorimotor regularities. Indeed, for someone whose phenomenal color qualities remained rotated and did not revert to the genuine color phenomenology, i.e., for whom tomatoes continued to look blue, but did not reappear as red, this may be the case, because perceptual learning, here resulting in action-sensation coupling, is a relatively slow process and its timing varies from one individual to another (Goldstone 1998; Seitz & Watanabe 2005). Such an explanation remains in line with the sensorimotor account of perception and cannot be excluded without further studies. On the other hand, it may be also possible that the development of adaptation under rotation took place unconsciously and therefore was not reported by the subjects.

4 Atypical color conditions in synesthesia

The lessons for enactive theories of color perception, pointed to by Grush et al. in their target article, may also be expanded by including challenges constituted by other atypical color conditions, namely synesthetic color experiences.

Synesthesia is traditionally considered to be a phenomenon in which the stimulation of one sensory or cognitive pathway (the inducer) elicits involuntary and consistent sensory experiences (the concurrent) in the same or another modality (Baron-Cohen et al. 1987; Baron-Cohen & Harrison 1997; Ramachandran & Hubbard 2001a, 2001b). As a result, the stimuli corresponding to the inducer and the experiences associated with the concurrent form a highly integrated percept—a phenomenally-unified experience which may cover not only sensory modalities, but also various mental domains including conceptual, emotional, bodily, and motor aspects (Mroczko-Wąsowicz & Werning 2012; Mroczko-Wąsowicz 2013). Such unification incorporates the central system and early stages of processing. Some synesthetes see colors when dealing with letters or numerals. Individuals with another kind of synesthesia perceive colored patterns in space when hearing sounds. The prevalence of the phenomenon depends on the particular type of synesthetic association, with grapheme-color synesthesia being the most common (Cytowic & Wood 1982; Mroczko-Wąsowicz & Nikolić 2013).

Color sensations are the most frequent synesthetic concurrents (Marks & Odgaard 2005), demonstrating color opponent properties and neural representations more or less similar to veridical color experiences (Nikolić et al. 2007; Hubbard et al. 2005; cf. Hupé et al. 2012; Van Leeuwen et al. 2010). For some forms of synesthesia color concurrents may also originate from information processing in regions of the cortex other than the visual. Recent neuroimaging studies demonstrate that synesthetic colors for numbers or mathematical formulas may also be produced when the visual cortex is not involved, i.e., by the activation of temporal, parietal, and frontal brain areas (Bor et al. 2007; Hupé et al. 2012; Brogaard et al. 2013). This suggests that information processing in non-visual brain regions may be a source of concurrent colors and therefore some forms of synesthesia can be seen as high-level perception proceeding via non-standard mechanisms. Such high-level synesthetic color perception for mathematical skills, though quite unusual, may provide supportive evidence for the conception of phenomenal liberalism and cognitive phenomenology.

5 Synesthetic colors and sensorimotor enactivism

Given that synesthesia, similarly to the color rotation gear, involves systematic distortions of color perception that are consciously experienced by the subjects, analyzing synesthetic experiences appears relevant in the context of the present discussion. This is why proponents of the sensorimotor theory of color perception might be interested in examining whether their postulates also apply in cases employing such synesthetic color-addition gear (cf. Hurley & Noë 2003; Fingerhut 2011; Mroczko-Wąsowicz & Werning 2012; Seth 2014; Ward 2012). The relevant propositions of enactivism may be stated as follows:

a. determining the modality of perceptual experience by specific sensorimotor signature (i.e., dependency between sensory stimulations and the activity of the perceiver, including their motor actions, bodily changes, or behavioral skills), as well as a necessary possession of such sensorimotor knowledge of contingencies enabling any perception;

b. flexibility of perceptual experience manifested in the ease of its modification and adaptation based on learning a new set of sensorimotor contingencies (Noë 2005);

c. and finally epistemic reliability of conscious perceptual experiences and their counterfactual richness (Metzinger 2014; Seth 2014; see also Seth this collection).

The above basic assumptions underlying sensorimotor enactivism of perception may be challenged by synesthesia in the following way:

A. Synesthetic concurrent percepts (e.g., visual experiences) are generated internally, not via a direct relation of a synesthete with the surrounding environment. They are triggered without employing the regular sensorimotor signature related to these concurrents, like eye saccades in normal vision. For such permanent inducer-concurrent couplings, the concurrent modality and its experiences are never related to their normal sensorimotor signature.

B. Synesthetic associations cannot be learned or adapted to, in contrast to various manipulations of sensory input such as, for example, spatial displacement, color inversion, or auditory-visual sensory substitution (sometimes called an artificial synesthesia), which are used by sensorimotor enactivists as examples of the perceptual system's adaptation involving an appropriate adjustment of sensorimotor contingencies. Unlike the majority of learned pairings, synesthetic associations are rigid and not flexible enough to adapt, irrespective of the amount of exposure to contradictory experiences or training (Baron-Cohen et al. 1993; Deroy & Spence 2013).

C. As a final point, although synesthetic colors are reported to be as vivid as non-synesthetic colors, synesthetes immediately detect the difference between them, which confirms the absence of perceptual presence or phenomenal transparency in synesthesia, meaning its opacity or experiential unrealness, which is the availability of earlier processing stages to attention (Metzinger 2003a, 2003b, 2014; Seth 2014).

As a kind of reply to these challenges, sensorimotor enactivits could claim that enactivism focuses on standard perceptual mechanisms and therefore has difficulties explaining perception-like experiences in synesthesia, as well as that synesthetic concurrents (often colors) lack some important features of typical perceptual experiences and properties of sensorimotor engagement, e.g., corporeality. However, this would not really be explanatory. One possible way of vindicating how the enactive theory could accommodate such atypical non-adaptive color conditions is to claim that there is actually no need for synesthetic colors to adapt, because they do not carry any information about the colors of objects in the synesthetes' environment —whereas adaptation is a retrieval of how things are colored. To put it in enactive terms, synesthetic colors do not figure in patterns of appearance reflecting dynamic relations between perceiver, object, and light (Ward 2012). Unlike the rotation gear, synesthesia does not determine the way things appear to the perceiver; i.e., the way worldly objects and surfaces modify the light is not affected.

6 Discussion

As concluded by Grush et al. the results obtained in their study show that color experiences changed in the early stage of application of the rotation gear and became stable, that is, they adapted to color constancy in the late rotation stage, without however consistently showing significant phenomenal adaptation by the end of the test. The investigators leave open a potential explanation of this outcome. The difference between this result and other studies, in which achieving phenomenal adaptation to spatial displacement or luminance inversion was more successful, may suggest that color sensations are special properties of early visual processing relatively difficult to phenomenally adapt as well as more resistant to penetration and manipulation by cognition (Fodor 1983; Pylyshyn 1999; Brogaard & Gatzia forthcoming; but cf. Macpherson 2012; Siegel 2012; Vetter & Newen 2014). At least this seems to be the case for the general population.

Synesthesia, although not considered to be an adaptive plastic phenomenon, may be a case in which some modifications take place, such as cognitive penetration of perception including early sensory processing. Synesthetic colors are frequently modified by cognitive operations, conceptual contents, contextual expectations, linguistic modulation, cultural factors, and other semantic knowledge mechanisms (Dixon et al. 2000; Simner 2007, 2012; Meier 2013; Mroczko et al. 2009; Mroczko-Wąsowicz & Nikolić 2013, 2014). Since synesthetes are able to penetrate this early aspect of vision it would be interesting to investigate whether synesthetically-perceived colors change under rotation. If so, is this in the same or in a different way to non-synesthetic, phenomenally-transparent colors?

Synesthetic colors are in some respects similar to the color experiences of rotation-gear wearers. In both cases, subjects are aware of the fact that what they see is not reliably colored, i.e., that their abnormal color experiences are not actual colors of the surroundings. On the other hand, these color experiences differ remarkably from each other. Whereas rotation gear wearers' color experiences are able to adapt to fall in line with what the subjects know to be true about colors of the things around them, synesthetes' color experiences do not display such flexibility. Thus, a theoretically founded hypothesis is that irrespective of the form of color synesthesia to be used in a color rotation experiment (e.g., grapheme-color, sound-color, time unit-color synesthesia) synesthetic colors would not alter.

Admittedly, the sensorimotor theory of color has difficulties explaining many of the features of the phenomenon of synesthesia, but this does not mean it is completely useless in the context of synesthesia. The theory could be used to account for the asymmetry in adaptation capability between those experiencing synesthetic and non-synesthetic colors. From the perspective of the enactive view of color, it could be proposed that the rotation gear interferes with regular color perception, because the equipment introduces a new set of sensorimotor dependencies. This is the reason why after wearing the rotation gear for some time and acclimatizing to the conditions, the rotated colors begin to appear normal, that is, the subjects' ability to perceive original colors returns—such that phenomenal color adaptation under rotation takes place. Unlike the rotated color perception of non-synesthetes, synesthetic subjects (associators) do not experience their additional colors as attributed to perceived objects but as seen in their "mind's eye". Therefore the concurrent colors do not affect their ability for regular color vision. An explanation of why there is no phenomenal color adaptation in synesthesia could be that synesthetic colors just fail to adapt because they do not need to make room for non-synesthetic colors (cf. Ward 2012). Thus, in line with the sensorimotor account, we could interpret the difference between ordinary color perception and color synesthesia as a difference between real and seeming engagement. However, another type of synesthetes, projectors, who see colors as projected onto inducing objects, may require a different explanation. Since this group of synesthetes demonstrates an external frame of reference for their synesthetic colors, projectors' phenomenal color adaptation under rotation might be comparable to the adaptation of non-synesthetes. A testable empirical prediction here would be that it is possible for projector synesthetes' colors to adapt after using a rotation equipment specially adjusted to interfere with internally-generated concurrent color experiences. Depending on the outcome of this prospective study, which could be designed in such a way that it would take into account all the differences related to color phenomenology, the sensorimotor theory of color may gain new insights into the threat of synesthesia.

What sensorimotor enactivism can also learn from studies on phenomenal adaptation in various perceptual conditions is that the notion of "phenomenal adaptation" applies to some conditions, but not others. There may also be different senses of the notion, and apart from "adaptation of the sensory sort" a rigorous analysis should consider "adaptation in the cognitive aspects of experience"—an expansive interpretation supported by phenomenal liberalism and cognitive phenomenology. In addition, the extent to which the phenomenon of adaptation may develop varies among various perceptual conditions. No matter the exact magnitude of the adaptive effects discussed, the very existence of phenomenal adaptation to alterations of sensory input, or its general lack, needs to be fully integrated by philosophical theories, especially by sensorimotor enactivist theories of perception that attempt to account for all the dynamics related to perception. This adaptation highlights that perceptual experience is more flexible and variable than usually presumed.

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Phenomenology, Methodology, and Advancing the Debate

A Reply to Aleksandra Mroczko-Wąsowicz

Rick Grush

The following topics are briefly discussed: First, the different senses of what counts as phenomenal, and in particular how this might influence how our results are described; second, the methodological limitations of our original study; and finally, some ways that the commentary by Mroczko-Wąsowicz charts out potential theoretical advancement of the results we presented in our study.

Keywords
Methodology | Phenomenology | Subjective report | Synesthesia

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1 On the nature of phenomenology

First, as Mroczko-Wąsowicz quite rightly points out, there are different understandings of what *phenomenology* is, with concomitant differences in what *phenomenal adaptation* might mean. The distinction drawn is between phenomenal conservatism, and phenomenal liberalism; the former being constrained to the vicinity of sensory features, and the latter including various cognitive phenomena, such as expectations and associations, among others.

We chose to use the term in the more restrictive sense for a number of reasons. First, as the more restrictive of the two, it is less controversial that what is included counts as genuinely phenomenological. Second, in many circles at least, the more restrictive understanding seems to be what people generally have in mind. The more liberal understanding is one that is endorsed more commonly only among specialists.

What I am about to say may be a matter of splitting hairs – and so I ask for forgiveness in advance. I am in complete agreement that the distinction is a valuable one to make, and that in our original article we just ran with the more restrictive definition. That said, it doesn't seem to me that with this distinction in hand one is raising "alternative interpretations" of our results; rather one is providing a different way of *describing* the same result. On a conservative definition of what counts as phenomenal, we did not find phenomenal adaptation. But if one adopts a liberal understanding of the term that includes various cognitive phenomena, then it would be correct to say that we did, in fact, find some phenomenal adaptation. So long as there is clarity on what exactly was found, and on how one intends to use the key terms, then this shouldn't be cause for confusion or concern.

Where things could get interesting would be on a possible third way to understand phenomenal – call it the *radical* understanding. On the radical view, there is nothing to phenomenology other than the sort of cognitive phenomena that the liberal view intended to add to the more narrowly sensory understanding. For one who holds such a view, we may very well have found the beginnings of phenomenal adaptation *tout court* when we found the beginnings of elements of cognitive adaptation.

This hairsplitting aside, I couldn't agree more with Mroczko-Wąsowicz's point that when getting into the details of discussions about phenomenal adaptation, a solid understanding of the different ways that the key terms might be understood is crucially important, and in this respect her commentary is an excellent supplement to the discussion we provided.

2 On methodological limitations

Mroczko-Wąsowicz goes on to, quite reasonably, point to some of the shortcomings of our pilot study. In fact, we pointed out many of these same shortcomings ourselves. There are a couple however that are worth saying at least a bit about.

Mroczko-Wąsowicz points out that some of our findings are based on subjective report, and that there are "doubts about whether subjective reports are trustworthy." While in general this is entirely correct, there is a sense of phenomenal adaptation according to which what we were studying is precisely *how things would seem to the subject.* It is undoubtedly the case that even in such situations one is not *limited to* what subjective report might have to say on the matter. Indeed, this is among the reasons we included other experiments as part of the protocol. But the phenomenon that I *subjectively notice and can report on* when I adapt to the spatial distortion of new corrective glasses, or to the color distortion of blue-blocking sunglasses is an interesting one, and one might reasonably wonder if one can get an analogous adaptation effect – the same subjectively noticeable and reportable effect – with respect to rotated colors.

This is related to a second point. Mroczko-Wąsowicz echoes our claim that it is a shortcoming of the study that the researchers themselves were subjects. Surely it is the case that knowledge of the experiment and the phenomena to be studied can bias the results. Of course I agree completely with that.

Nevertheless, I am reminded of a point made in conversation by Vilayanur Ramachandran. In a moment of venting about some objections made to some of his results, he hypothesized that he could show psychologists a talking pig and they would scoff that it was an n of 1.

In the present case, it is true that having the experimenters themselves be subjects effects the results. But even so, if it turned out that I or the other subject JK did end up in a state that seemed to us to be one of phenomenal adaptation, then this would still be interesting, because if nothing else it would demonstrate that we could get the effect in anyone if we just briefed them on the experiment beforehand. If I hypothesize that hitting myself on the head three times with a baguette will make me able to speak fluent French, and I do the experiment and it *does*, this is an interesting result even if I was both experimenter and subject.

In any case, Mroczko-Wąsowicz and I are in a great deal of agreement about the limitations created by the methodology of our pilot study, and these limitations need to be kept firmly in mind when anyone ventures to interpret our findings or follow up on them.

3 Advancing the debate

The final set of points made by Mroczko-Wąsowicz concerns synesthesia, and in particular how the phenomenon presents an interesting complement to the sort of phenomenon we studied. When we were initially brainstorming the experiment we discussed what might happen if a synesthete were to wear the rotation gear. But that line of speculation never got past the brainstorming stage, since just doing it with ourselves proved enough of a challenge. While it has some significant differences from synesthesia, we did make an attempt to see whether the McCollough effect would adapt. But the subjective effect was very small, and didn't last long enough into the protocol to get any data at the time when there might have been some adaptation.

Mroczko-Wąsowicz makes some fascinating points about how our study and synesthesia complement each other in interesting way that would be strong motivation for anyone following up on our study to try to include some synesthetes among the test subjects.

4 Conclusion

We tried to make our initial article streamlined and not burdened with too much detailed theoretical discussion. Since we hope the interested parties will include not only philosophers but also psychologists and cognitive scientists, the thought was to present the results, which we thought were quite interesting and suggestive, and leave the more detailed theoretical discussions and possible follow-up experiments to others. In this respect Mroczko-Wąsowicz's commentary is exactly the sort of detailed theoretical follow-up we hoped others might be inspired to produce on the basis of our results. I am grateful to her for fantastic commentary.