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

Commentator

Aleksandra Mroczko-Wąsowicz
mroczko-wasowicz@hotmail.com
國立陽明大學
National Yang Ming University
Taipei, Taiwan

Target Authors

Rick Grush
rick@mind.ucsd.edu
University of San Diego
San Diego, CA, U.S.A.

Liberty Jaswal

Justin Knoepfler

Amanda Brovold
abrovold@miracosta.edu
MiraCosta College
Oceanside, CA, U.S.A.

Editors

Thomas Metzinger
metzinger@uni-mainz.de
Johannes Gutenberg-Universität
Mainz, Germany

Jennifer M. Windt
jennifer.windt@monash.edu
Monash University
Melbourne, Australia

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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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