
COLOUR VISION AND SEEING COLOURS

WILL DAVIES

Abstract

Colour vision plays a foundational explanatory role in the philosophy of colour, and serves as perennial quarry in the wider philosophy of perception. I present two contributions to our understanding of this notion. The first is to develop a constitutive approach to characterising colour vision. This approach seeks to comprehend the nature of colour vision qua psychological kind, as contrasted with traditional experiential approaches, which prioritise descriptions of our ordinary visual experience of colour. The second contribution is to argue that colour vision does not constitutively involve the ability to see colours, in a natural and categorically committed sense. I argue that two subjects exactly alike in respect of their constitutive colour vision abilities could differ in respect of whether or not they have categorical perception of colour. The argument is supported by thought experiment and dissociations observed in cognitive neuropsychology. The argument also bears connections to recent neo-Whorfian accounts of colour categorisation.

1. Introduction

2. Colour Vision, Experience, and Natures

3. The Central Argument

3.1. Colour constancy and discrimination

3.2. Dissociating colour vision and categorical perception for colour

4. Whorf and the View from Cognitive Neuropsychology

5. Conclusion

1. Introduction

What does colour vision, by virtue of its nature, enable us to see? A straightforward answer is that colour vision enables us to see colours. What does this mean? Another straightforward answer is that ‘seeing colours’, at least in humans, means seeing red, orange, yellow, green, blue, and so on. So far, so simple.

Things are not quite so simple, however. The most natural reading of ‘seeing red, orange, and yellow’ is categorically committed, in that it implies the ability to see, in a sense not yet explained, the colour categories red, orange, and yellow. Thus understood, the ability to see colours implies the possession of categorical perception for colour (CP). CP is a vivid feature of our ordinary experience of colour, as canonically manifested in the banded or segmented appearance of a rainbow. Colour category terms such as ‘red’, and derivatives such as ‘reddish’ and ‘shade of red’, also provide our primary means of communicating about colour and colour vision. Despite the experiential vividness and communicative pervasiveness of colour categories, however, I believe that colour vision should be dissociated from CP for colour. Our normal human visual ability to perceive colour has a constitutive nature that is distinct from that of our ability for colour categorisation. To put the claim in its most provocative form, colour vision does not, by its nature, confer the ability to see colours, in the natural, categorically committed, sense.

The central argument is as follows. It is constitutive of possessing colour vision that an organism possesses the ability to achieve colour constancy; colour constancy is characterised by abilities to discriminate visually between both the surface spectral reflectance properties of objects and wavelength properties of the ambient illumination; it is possible that colour constancy qua SSR and wavelength discrimination, hence colour vision, could be completely dissociated from CP for colour; therefore, CP for colour does not form

part of the nature of our colour vision abilities. This argument will be presented in Section 3. The rationale behind the argument's focus on the constitutive nature of colour vision will be discussed in Section 2.

In Section 4, I provide further motivation for the key dissociative premise of the argument by discussing some fascinating cases from cognitive neuropsychology. In cases of optic aphasia for colours, subjects retain normal visual discriminatory abilities with respect to colour while becoming severely impaired in their performance on colour categorisation tasks. In the evocative phrase of Goldstein and Gelb ([1918]), such subjects have an 'impairment of the categorical attitude' towards colour. These cases suggest that the dissociative possibility on which the argument rests is not only coherent, but perhaps not even that distant. I shall also bring out some connections between my argument and recent neo-Whorfian views of colour categorisation in cognitive psychology, on which CP is taken to be partly influenced by linguistic colour classification. While the argument is strictly independent of these contentious empirical issues, the discussion should present fruitful new points of contact between philosophical and scientific work on colour perception.

2. Colour Vision, Experience, and Natures

My central theses are, first, that colour constancy is constitutive of colour vision, and second, that CP for colour does not form part of this constitutive nature. Two preliminary questions arise: Why the interest in colour vision? And why the emphasis on the constitutive nature of colour vision? As for the first question, colour vision plays a foundational explanatory role in the philosophy of colour. Although not always made explicit, colour vision is assumed to provide a privileged source of evidence about colour ontology, surely the central issue in this area. This assumption has roots in Aristotle's claim that colour is the 'special object' of

vision, by which he meant that it is impossible to acquire knowledge of colour via any other sense modality. In contemporary philosophy, a pervasive and related thought is that in order to know what colour properties are, we must first understand how colours are represented in visual perception.¹ Debates about colour ontology therefore have centred on the question as to which properties (and relations) are represented in colour vision and whether or not these properties (relations) correspond to genuine properties (relations) of the ordinary objects that we perceive. Such questions, among other things, have prompted significant interest in colour vision within the wider philosophy of perception. Colour vision serves as the go-to source of examples in this area, a perennial quarry for philosophers seeking to clarify the nature of perception and consciousness.

The philosophical project of understanding colour vision clearly overlaps significantly with work in vision science. Reassuringly, the last twenty five years or so has seen a remarkable increase in philosophical engagement with results from physiological, psychophysical, and computational studies of colour vision. While increasingly empirically informed, however, it nonetheless remains extremely common, if not standard, in philosophical contexts to adopt a broadly pre-theoretical, experiential, conception of colour vision, at least as a starting point for debate. On this experiential view, colour vision is characterised by our having conscious visual experiences of this distinctive type, or by objects appearing in these distinctive ways in experience, where the demonstratives are intended to pick out aspects or qualitative dimensions of our visual experience that are clearly distinguishable from those aspects corresponding to our experience of shape, texture, motion, and so on. As a foundation for work in the philosophy of perception, the experiential conception licenses an approach to debates about perceptual natures, abilities, constancies,

¹ See Boghossian and Velleman ([1991], p. 106), Byrne & Hilbert ([2003], p. 5), Hilbert ([1992], p. 359), Jackson & Pargetter ([1987], p. 68), and Strawson ([1979], p. 109).

and contents that is thoroughly phenomenological and introspective in flavour. As a foundation for ontology, the experiential view implies that theories of colour ultimately should be answerable to features of our ordinary visual experience of colour. A *prima facie* sufficient reason to reject some account of colour ontology, then, would be that it fails to recover or respect some aspect of ordinary conscious colour appearances. Such is the current and historical orthodoxy in the philosophy of colour.²

The foregoing characterisation of the experiential view of colour vision probably won't ring true for everyone. Nonetheless, I believe it comes close enough to capturing some dominant philosophical tendencies to serve as a target in what follows. The central methodological aim of this paper is to develop an alternative to this orthodox experiential approach. My proposal is that our philosophical starting point instead should be an account of the nature of colour vision *qua* psychological kind. The kind in question will be a type of ability or capacity: colour vision is an ability that subjects possess and that is exercised when they visually perceive colours, much as your ability to understand English is a capacity that is being exercised while reading this sentence. In seeking an account of the nature of colour vision, then, we seek a characterisation of this distinctive psychological ability; an ability shared in common between all actual and possible colour perceivers. I call this the constitutive approach to theorising about colour vision.

Thus stated, the constitutive approach is in fact consistent with a certain type of experiential view of colour vision. An advocate of the experiential view might endorse the constitutive approach and yet persist in claiming that colour vision *qua* psychological kind

² Some randomly chosen examples of the experiential orthodoxy in action: Armstrong ([1987], pp. 36-37), Boghossian & Velleman ([1989], p. 85), McGinn ([1996], pp. 541-542), Tye ([2000], pp. 152-153). Armstrong ([1978], p. 125) notes that this approach has roots in Hume, for whom colour 'phenomenology decides the question of ontology'. See Akins & Hahn ([2000], p. 233) and Matthen ([2005], p. 167 ff) for discussion.

constitutively involves the ability to undergo this and that type of visual experience.³ For reasons that will become clear in the next paragraph, I think that any such constitutive-cum-experiential view would be extremely implausible. The key point for now is simply that unlike mainstream philosophical approaches, the constitutive approach does not force or require an experiential conception of colour vision. On the constitutive approach, a philosophical account of colour vision is not beholden to, or necessarily constrained by, features of our ordinary colour experience. This approach leaves open many differing views of colour vision, each of which might have interesting and unexplored philosophical consequences. As I discuss later, the view that I find most plausible is that the constitutive bedrock for the possession of colour vision is the ability to achieve colour constancy. The ensuing argument draws out a surprising consequence of this constitutive thesis: that colour vision thus understood does not involve the ability to see colours in the categorically committed sense. Even if the reader does not agree with my constancy-centric constitutive starting point, however, the argument should still be of interest as an illustration of the constitutive approach at work.

There have been some important steps in the direction of the constitutive approach in the recent philosophical literature, (and hence away from the orthodox experiential view described above). For example, Thompson and colleagues ([1998]) were among the first to bring comparative, interspecies, studies of colour vision to the attention of philosophers. This work highlighted the great variety of colour-related capacities encountered throughout the animal kingdom, and emphasised the fact that colour vision is a significant psychological kind featuring in actual empirical attributions and explanations across a diverse range of

³ The approach is likewise consistent with the view that CP for colour is partly constitutive of colour vision. The force of my argument lies in its denial of this possibility.

organisms.⁴ Such comparative studies in turn provided one of the key motivations for Matthen's ([1999], [2005]) pluralist account of colour ontology. These philosophers bucked the major historical trend by deemphasising the evidential role of normal human experience in understanding colour vision and, consequently, colour. Such considerations breached the experiential orthodoxy, and furthermore undermine any constitutive-cum-experiential view of the sort adumbrated above. While these developments are undoubtedly significant, however, in my view their focus on the implications of animal colour vision has obscured a crucial point much closer to home. We can all agree that ordinary human colour experience provides an unsuitable model for the colour vision capacities of other animals; but I would add that ordinary colour experience cannot even be taken as a presumptive guide to the core nature of our very own colour vision abilities. It is this last, seemingly redoubtable, vestige of the experiential view that I seek to undermine in what follows.

In voicing scepticism about the informativeness of ordinary colour experience for a constitutive account of colour vision, I am not claiming that phenomenology is irrelevant to our understanding of this kind. In empirical methodology, the study of visual perception obviously couldn't get off the ground without it. I allow, moreover, that visual experience plays an inalienable role in providing our initial identifying characteristics of colour vision qua psychological kind. This point is compatible, however, with the claim that colour vision is not constitutively associated with features of our ordinary conscious experience of colour. This is by now a familiar point in the philosophy of science: explanatory kinds are often, if not typically, initially identified via features that ultimately turn out to be merely superficial or contingent features of those kinds. Once such an identification has been made, an account of a kind's nature may allow instances to be identified or hypothesised in circumstances in

⁴ The significance of comparative studies of colour vision is now more widely appreciated. For example, see Allen ([2009]), Byrne & Hilbert ([2003], pp. 15-16), Cohen ([2009], pp. 26-29), and Kalderon ([2007], p. 578).

which the initial means of identification are partially, or even completely, absent.⁵ As such, whatever the role of experience in acquainting us with colour vision qua psychological kind, we should not attempt straightforwardly to infer or ‘read off’ the nature of these visual abilities from features of our ordinary experience of colour. That our ordinary experience of colour typically or even canonically displays some feature *F* does not entail that *F* is a constitutive feature of our colour vision capacities. That is to say, not all functionally significant features of colour experience will be constitutively necessary for the possession of colour vision.

These last claims presuppose that colour experience has a latent and underappreciated complexity. Although colour is traditionally conceived as a paradigmatic ‘low-level’, ‘simple’, or ‘basic’ perceptible feature, colour experience in fact reflects the upshot of a wide range of perceptual, structural, organisational, recognitory, and broadly conceptual abilities or processes. As in other areas of cognition, this composite nature is not transparent to the naïve subject, whose experience of colour is monolithic and unified. Patterns of breakdown and dissociation among such processes in impaired subjects, while clearly unfortunate, therefore provide one of the few keys to unlocking this complexity. Two processes that are ordinarily reflected in colour experience, and which will be central in what follows, are colour constancy and CP for colour. In the next Section, I argue that it is possible that the processes required to maintain colour constancy could become completely dissociated from those involved in colour categorisation. I also claim that colour constancy is constitutively both necessary and sufficient for the possession of colour vision. It follows that colour vision qua constancy can be dissociated from our ability to perceive superordinate colour categories such as red and orange. If this is correct, then at least one pervasive and vivid feature of our

⁵ See Shea ([2012]) for an interesting application of this thought to the study of phenomenal consciousness itself.

ordinary experience of colour is not, strictly speaking, part of the nature of our ability visually to perceive colour. The feature in question is that of seeing colours, in the categorically committed sense.⁶

3. The Central Argument

My central argument is as follows.

1. Necessarily, for any organism x , x possesses colour vision if and only if x possesses the ability to achieve colour constancy. (CC)
2. Therefore, necessarily, for any organisms x , y , x and y are alike in respect of their core, constitutive, abilities visually to perceive colour if and only if x and y are alike in respect of their ability to achieve colour constancy.
3. Necessarily, for any organisms x , y , if x and y are alike in respect of their ability to discriminate visually among a) the surface spectral reflectance properties (SSRs) of objects in the environment, and b) the wavelength properties of the ambient illumination, then x and y are alike in respect of their ability to achieve colour constancy.⁷ (DV)
4. Therefore, necessarily, for any organisms x , y , if x and y are alike in respect of the visual discriminations they are able to make between SSRs and the wavelength properties of the ambient illumination, then x and y are alike in respect of their constitutive colour vision abilities. (2, 3)

⁶ Compare Akins ([2001], p. 110), who challenges the assumption that ‘what we see consciously provides the *raison d’être* of the spectral system – that the purpose of the colour system is to produce “the colours”’.

⁷ Note that in fixing on SSRs and properties of the illuminant, I am not prejudging the question of colour ontology. My approach is similar to Matthen ([1999], p. 78), who presents a broadly functional characterisation of colour vision in terms of wavelength discrimination, but whose view clearly does not imply that colours are wavelength properties.

5. It is possible that an organism with exactly the same visual discriminatory abilities as a normal human could completely lack CP for colour.

6. Therefore, it is possible that two organisms exactly alike in respect of their constitutive colour vision abilities could differ in respect of whether they possess CP for colour. (4, 5)

7. Therefore, CP for colour does not form part of the constitutive nature of normal human colour vision abilities.

Premises one and three, CC and DV, are complementary and need to be understood in conjunction. CC claims that colour vision constitutively involves the ability to achieve colour constancy. This raises the question as to how colour constancy itself should be characterised. DV presents a discriminatory view, on which one's ability to achieve colour constancy supervenes on one's visual discriminatory abilities with respect to SSRs and wavelength properties of the illuminant. Together CC and DV imply premise 4, on which an organism's constitutive colour vision abilities supervene on its visual discriminatory capacities. Premise 5 is the key dissociative claim that it is possible to dissociate an organism's capacity to perceive colour thus understood from its ability for CP for colour. The following subsections address these claims in more detail.

3.1. Colour constancy and discrimination

The constitutive approach holds that our starting point for philosophical theorising about colour vision should be to understand the nature of colour vision qua psychological kind. As noted above, this general approach is consistent with many differing views of colour vision, not all of which can be explored here. My preferred view is CC. The view that perceptual constancies mark constitutive bedrock for visual perception has been defended at length in

recent work by Burge ([2010]) and in Davies ([unpublished]). In the philosophy of colour, Hilbert ([1992]) has also defended a thesis close to CC.⁸ I take this work for granted in what follows, and hence shall say fairly little in defence of CC. Readers who reject CC need not be deterred, however, for two reasons.

First, even without CC my argument warrants the conclusion that colour constancy, if not colour vision per se, does not constitutively involve the ability to see colours in the categorically committed sense. This weaker thesis still should be of interest to philosophers working on colour, and to those interested in the nature of perceptual constancy more generally. Second, although it is philosophically revisionary, the view of colour vision implied by CC and DV is by some, more empirical, lights reassuringly conservative. Among vision scientists, the textbook standard for the possession of colour vision is the ability to discriminate differences in wavelength properties of light.⁹ My view bears some similarities in taking colour vision to supervene on capacities visually to discriminate both wavelength properties and SSRs of objects in the environment. (As will become clear, however, my view employs a representational notion of visual discrimination, which is richer than the behavioural, operational, notion assumed in vision science. DV thus implies that colour constancy is a resolutely representational phenomenon.) If the reader therefore can stretch to accepting premise four, then this together with premise five will suffice for my conclusion.

In brief, the central motivation for CC is that the achievement of perceptual constancy with respect to some feature – shape, motion, size, depth, colour – marks the transition from

⁸ Smith ([2002]) also argues that perceptual constancy is necessary and sufficient for perception. As Burge ([2010], p. 409n) notes, Smith's view of constancy is overtly phenomenological in character and is not aimed at understanding the nature of constancy qua psychological kind. Thompson et al. ([1998], p. 380) agree on the centrality of colour constancy to colour vision, but claim in addition that colour vision 'involves' additive colour mixture and colour contrast. They do not explain why additive colour mixture should be necessary for colour vision. Akins & Hahn ([2014]) have also stressed the importance of chromatic contrast for colour vision. In my view, there are important but under-theorised connections between colour constancy and colour contrast. I hope to discuss this in future work.

⁹ For example, see Gordon and Abramov ([2001], p. 93). Compare the aforementioned functional characterisation in Matthen ([1999], p. 78).

mere sensory registration of, or informational sensitivity to, features of the proximal stimulus, to fully fledged representational sensitivities to distal features of the environment.¹⁰ In the case of colour constancy, the transition is from those organisms that possess wavelength sensitive cells or organs, but whose associated abilities and behaviours are subsumable under non-cognitive, non-representational, notions of phototaxis, photokinesis, phototropism, and so on; to organisms that possess abilities to extract from the proximal stimulus reliably veridical representations of distal features of the environment, and whose abilities and behaviours thus come to be explicable only via the rich cognitive, representational, explanatory resources of visual perceptual psychology.¹¹ Visual representations of distal features possess a primary biological and ecological significance in underwriting and guiding organisms' basic activities such as foraging, eating, initiating or avoiding predation, seeking out a mate, locating shelter, and so on. For this reason the central preoccupation of much vision science has been to explain how perceptual constancies are achieved.¹² Palmer and colleagues ([2003], p. 314) express a common view,

In our opinion, constancy provides the single most crucial landmark in visual processing. It is the set of visual operations whose presumed job it is to convert visual representations that encode image-based (retina-based) features into ones that encode environment-based (object-based) features... [M]any of the most crucial inferences the visual system must make are concerned with the logical leap from 2-D representations to some more ecologically useful representations that contain explicit information about properties of external, environmental objects.

¹⁰ On the distinction between sensory registration and perceptual representation, see Burge ([2010], pp. 315-319).

¹¹ For discussion of taxes and their relevance to understanding the lower, pre-constancy, borders of visual perceptual representation, see Burge ([2010], p. 326 ff).

¹² According to Thompson ([1995], p. 43) the achievement of perceptual constancy is 'the central information-processing problem' studied by computational theories of vision, which have the strongest claim to the title of Kuhnian 'normal science' in the study of perception.

The ability to achieve constancy thus marks a significant cut – a difference in kind– among organisms with sensory capacities. The proposal is that this cut marks the boundary between the merely sensory, and the genuinely perceptual. To borrow from Burge ([2010], p. 413), ‘perceptual constancies are paradigmatic marks of objectification. I think that their presence in a sensory system is necessary and sufficient for the system’s being a perceptual system.’

In emphasising constancy as the core constitutive standard for colour vision, I am not denying that colour vision as instantiated in humans and other species displays many other functionally significant features besides constancy. Others may wish to emphasise these different features. In many cases, the descriptive or explanatory context may indeed demand a more inclusive approach. The rationale behind CC, however, is to provide a maximally general, cross-cutting, characterisation of colour vision; a standard that unifies the many varied colour vision systems encountered across the animal kingdom. As such it is telling that all animals currently known to possess colour vision seem to exhibit colour constancy to some degree. For example, comparative studies have found evidence for colour constancy in the honeybee (Neumeyer [1981]; Werner et al. [1988]), goldfish (Dörr and Neumeyer [2000]; Neumeyer et al. [2002]), butterfly (Kinoshita and Arikawa [2000]), and diurnal and nocturnal hawkmoth (Balkenius and Kelber [2004]), to name a few. Neumeyer ([1998], p. 347) infers from these findings that ‘colour constancy... is indeed essential for colour vision’. In contrast, although comparative studies have found signs of CP for colour in some non-human species, the evidence is far more limited and equivocal. Kelber & Osorio ([2010], p. 1622), for example, report that ‘other than in birds, and the limited evidence from fish, there is little convincing evidence for colour categorisation in other species, including non-human primates...’¹³

¹³ Kelber & Osorio do caution, however, that ‘application of suitable tests may well change this view.’

One possible objection to CC is that colour constancy is largely achieved on the cheap, in that it is attributable to very low-level, pre-representational, processes such as retinal adaptation. If colour constancy is in fact a predominantly pre-representational process, this would undermine the idea that constancy is constitutive of colour vision. In response, I take issue with the claim that colour constancy is solely or even predominantly attributable to processes of retinal adaptation. Such processes are doubtless important in many viewing contexts, but numerous studies indicate that subjects are capable of extremely reliable colour constancy judgements across changes in illumination that are too rapid to allow for significant adaptation.¹⁴

These points notwithstanding, my main issue with the objection is that there is no valid inference from ‘X is largely attributable to non-representational processes’ to ‘X is non-representational’. This inference slips from a claim about the mechanisms responsible for X, to a claim about the nature of X itself. I assume that many paradigmatically representational cognitive capacities – such as intentional action, reasoning, and linguistic understanding – are realised by a wide range of neural mechanisms, not all of which involve representation. The fact that an entire system, module, or process might have component mechanisms that are non-representational should not impugn the representational nature of the system, module, or process itself. Now as I understand it, perceptual constancy is a resolutely representational phenomenon. This reflects mainstream empirical assumptions, as seen in the above quote from Palmer and colleagues ([2003], p. 314). Even granting that some – perhaps even the majority – of the component mechanisms involved in achieving colour constancy are non-representational, then, this provides no good reason to doubt the representational nature of constancy qua psychological kind.¹⁵

¹⁴ For example, see Foster et al. ([1991]) and Foster et al. ([2001]). I discuss the limitations of adaptation-based conceptions of constancy in more detail in Davies ([forthcoming]).

¹⁵ For a survey of the multiplicity of mechanisms involved in colour constancy, see Smithson ([2005]).

Having proposed CC as a constitutive standard for colour vision, we must now confront the question as to how colour constancy itself should be characterised. This is a contentious matter, and the subject of ongoing debate. The default characterisation of colour constancy in both philosophical and empirical work is known as ‘appearance invariantism’. Invariantism characterises colour constancy as the phenomenon whereby objects visually appear approximately the same in respect of colour across changes in illumination. ‘Colour appearance’ here is to be understood in the quasi-technical sense familiar to vision scientists, as pertaining to the aspect of perceptual phenomenology represented by multi-dimensional colour appearance spaces, such as the standard three dimensional hue-saturation-lightness (HSL) space. On this view, then, a subject’s degree of colour constancy is determined by the extent to which these qualitative dimensions of visual experience – say, an object’s hue and saturation – remain invariant under changes in illumination. Information about the illuminant is not visually represented on this view: the standard line is that such information is ‘discarded’ or ‘discounted’ in the process of generating illumination-invariant colour appearances.

Against this naïve view, ‘variantists’ have argued that colour constancy cannot be grounded in appearance invariance, most notably due to psychophysical evidence that changes in illumination in fact produce quite significant variations in an object’s hue and saturation.¹⁶ On this view, information about the illuminant is not discarded by the visual system, but rather retained and reflected in the qualitative dimensions of colour appearance. In a broadly Helmholtzian spirit, variantists seek to characterise colour constancy by appealing to the representational outputs of putative, quasi-cognitive, processes of perceptual ‘inference’. On this view, the visual system supposedly ‘infers’ or otherwise derives

¹⁶ The classic empirical study is Arend & Reeves ([1986]). See Cohen ([2008]) for a variantist, neo-Helmholtzian, interpretation of these data.

representations of objects' stable, illumination-independent, surface colours, from patterns of illumination-dependent change in objects' phenomenal colour appearance.¹⁷

Invariantism and variantism mark the traditional poles in philosophical debates about colour constancy. I want to consider an alternative characterisation that has arisen in the empirical literature, but which has not received much philosophical attention. This is the operational view (OV) of Craven and Foster ([1992], p. 1360),¹⁸

[We present] an alternative and complementary property of colour constancy, as follows: The ability of a subject to correctly attribute changes in the colour appearance of a scene either to changes in the spectral composition of the illuminant or to changes in the reflecting properties of that scene.

According to OV, the key criterion for colour constancy is the possession of abilities to 'discriminate' a change in reflectance from a change in illumination. These abilities can be assessed in psychophysical tasks in which the subject is presented with a coloured stimulus with reflectance properties R_1 under illuminant A , proceeded either by the same stimulus under another illuminant B , or by a different stimulus with reflectance R_2 . The subject is then asked to push one of two buttons depending on whether they judge the change that has occurred to be in the surface properties of the stimulus, or in the illumination. High levels of colour constancy correspond to high degrees of accuracy in identifying changes in illumination and changes in stimulus reflectance as such. That is, subjects do well if a change from illuminant A to illuminant B is not confused or conflated with a change in the surface properties of the stimulus. Similarly, they do well if a change in stimulus reflectance from R_1 to R_2 is not conflated with a change in illumination.

¹⁷ Wright ([2013]) discusses such views under the label of 'projective' accounts of constancy.

¹⁸ Also see Foster & Nascimento ([1994]).

How does OV contrast with invariantism and variantism? Unlike invariantism, OV does not ground colour constancy in the stability of colour appearance across changes in illumination. As Craven and Foster ([1992], p. 1364) remark, ‘it may be irrelevant whether the colour appearance of an object does or does not change under a change in illuminant, providing that any changes that do occur can be correctly attributed’. Insofar as OV allows for constancy in circumstances of significant illumination-dependent change in colour appearance, it clearly has affinities with variantism. Unlike variantism, however, OV does not ground constancy in putative processes of perceptual inference from variant colour appearance to illumination-independent surface colour properties. Moreover, OV is not committed to the claim that colour constancy canonically or typically involves such illumination-dependent phenomenology. As I read the view, OV is strictly neutral on this issue. So long as the subject is capable of differentiating changes in illumination from changes in surface reflectance, then the degree of appearance (in)variance that she encounters is simply ‘irrelevant’ in evaluating her constancy capacities.

OV’s discriminatory characterisation is thus consistent with invariantist and variantist views of colour appearance, and indeed with other, more complex, views of the phenomenology of colour constancy.¹⁹ This phenomenological neutrality is appealing for those seeking a maximally general, cross-cutting, characterisation of colour constancy. As discussed elsewhere (Davies [forthcoming]), the empirical data suggest that neither invariantism nor variantism uniquely characterises the phenomenology of constancy. In contrast, it does seem that wherever we are inclined to attribute constancy, we should find robust capacities to discriminate changes in illumination from changes in surface reflectance properties. Absenting these capacities, an organism would be liable regularly to confuse or

¹⁹ In Davies ([forthcoming]), I argue that OV is consistent with ‘complex invariantism’, a view on which visual experience has qualitative dimensions for both material and lighting colour, numbering six dimensions in total.

conflate changes in illumination for changes in an object's surface properties, and vice versa. Such an organism would not display any evidence of having disentangled the respective contributions of these variables to its overall perceptual state: such an organism would lack colour constancy.

This last point suggests that OV presents at least a necessary condition on colour constancy: no capacity to discriminate between illumination and surface changes implies no colour constancy. Is the condition also sufficient? This suggestion is problematic, for there are strong reasons to think that discrimination, at least in the sense intended by OV, is not necessarily sufficient for colour constancy. Recall that OV is an 'operational' view of constancy, on which capacities to discriminate are explicitly linked to performance in a psychophysical task. On this view, a subject discriminates a change in reflectance from a change in illumination just in case she provides largely correct behavioural responses – in this case, button presses – in tasks of the sort described above. One might reasonably object, however, that discriminatory behaviour of this type does not necessarily suffice for the attribution of genuine perceptual, representational, abilities with respect to distal features of the environment. That is to say, it is conceivable that an organism could display such discriminatory behaviour, while altogether lacking genuine visual representational abilities.²⁰ Now of course we assume that all human subjects actually assessed in these experiments do possess such abilities, and that their task performance can be taken as evidence of their perceptual capacities. But the mere possibility of discriminatory behaviour in the absence of visual representation undermines the proposal that OV can characterise colour constancy qua constitutive standard for colour vision.

²⁰ This echoes Hilbert's ([1992]) central objection to the sufficiency of the wavelength discrimination criterion for colour vision. See also Matthen ([1999], p. 52).

The discriminatory view of colour constancy (DV) presented in premise 3 is designed to avoid these problems with OV.²¹ DV is clearly inspired by OV, and shares its empirical motivations. DV follows OV in characterising colour constancy via capacities visually to discriminate differences in distal properties. More precisely, an organism's ability to achieve colour constancy supervenes on its capacities to discriminate visually among SSRs of objects in the environment, and wavelength properties of the ambient illumination. Necessarily, any change in the degree of colour constancy that an organism is able to achieve in a given viewing context implies some underlying change in these visual discriminatory abilities. Whereas OV adopts a behavioural concept of discrimination, however, DV employs an inherently visual representational notion. On this view, *S* is able to discriminate visually between *X* and *Y* just in case *S* is able to form representations, within a perceptual subsystem that can be antecedently described as visual, with the veridicality conditions that *X* and *Y* are distinct, and moreover that these representations are reliably veridical within some suitably restricted range of actual and counterfactual cases.²² Here the relevant discriminatory responses are not patterns of behaviour, judgement, or report: the discriminatory responses are representational states of the visual system.

According to DV, then, an organism's colour constancy capacities supervene on its abilities to generate discriminatory perceptual representations of both SSRs and wavelength properties of the ambient illumination. It is important to note that what are being discriminated in this case are not objects, but rather property types themselves; more

²¹ Despite the order of presentation, DV is explanatorily prior to CC: we require a working characterisation of colour constancy, prior to claiming that colour constancy is constitutive of colour vision. In practice, however, philosophical attempts at characterising colour constancy inevitably draw on ongoing empirical research, much of which simultaneously provides motivation for CC. This does not create any vicious circularity, so long as we are careful to distinguish the project of extracting a maximally general understanding of 'colour constancy' as it occurs in such studies, from the project of inferring what these studies tell us about the nature of colour vision.

²² This model is inspired by Williamson's ([1990]) cognitive account of discrimination, on which to discriminate *a* from *b* is to activate the knowledge that *a* and *b* are distinct. My characterisation aims to preserve Williamson's insight that discrimination proper implies capacities for reliably veridical representation of distinctness, while doing away with the epistemic baggage.

accurately, property types as presented by their property instances. In discriminating between the reflectance properties R_1 and R_2 of objects a and b , then, my visual system does not simply represent that a and b differ in respect of reflectance: it (somehow) represents that the property types R_1 and R_2 are distinct. What form would these putative representations take? This question requires a paper in its own right, but for present purposes we can adopt an inclusive view. For example, one idea would be that the visual system represents something of the form ‘the surface property presented by this object differs from the surface property presented by that object’. Another possibility is that the visual system employs some as yet unknown type of direct representation of tropes or property instances, as in ‘this surface property differs from that surface property’. In both cases, the relation that is represented as holding between these properties also remains to be clarified. One possibility is that ‘differs from’ represents a brute relation of non-identity. Another possibility, which I find more plausible, is that this relation will be unpacked in terms of a direction and magnitude of difference in some quality space. However these issues turn out, the key overarching claim is that these visual discriminatory abilities are grounded in non-atomic, relational, representations within the colour vision system.

These clarificatory remarks bring out another important difference between DV and OV. According to OV, colour constancy requires the capacity to discriminate between two stimulus conditions or states of affairs: namely, the condition of having undergone a change in surface properties, versus the condition of having undergone a change in illumination. DV, in contrast, requires the capacity (somehow) to represent the types of surface property or illumination instantiated by these stimuli as distinct. By implication, DV requires the subject to be capable of visually representing types of surface property and illumination and, moreover, to discriminate dimensions of change in respect of these properties.

In saying that colour constancy requires the visual representation of both surface properties and the illuminant, once again I want to remain neutral on the precise types of representation involved, and on how these representations influence or determine the organism's visual experience of the scene. I allow, for example, that some organisms may explicitly represent both surface and lighting properties via qualitative dimensions of the phenomenology of visual experience. Indeed as I argue in Davies ([forthcoming]), this plausibly is often the case in normal human subjects. Another possibility, however, is that one or more type of representation is processed by nonconscious or subpersonal perceptual processes. However these issues turn out, the main claim for DV is simply that colour constancy requires some sort of visual representation of the illumination conditions, such as to undergird the organism's perceptual discriminations of changes in the illuminant. DV thus marks another significant departure from traditional models of constancy, on which illumination information is simply 'discarded' or 'discounted' in the process of generating a stable surface colour estimate.²³

DV is clearly hostage to empirical fortune in various ways. First, DV predicts that differences in respect of the degree of colour constancy that an organism can achieve in a given context should be reflected somewhere, somehow, in the organism's capacity to discriminate both SSRs and properties of the illuminant. The view therefore would be disconfirmed, for example, by evidence of significant impairments to colour constancy with largely preserved capacities visually to discriminate these properties. Second, eventually we

²³ A referee raised the following objection. Consider an organism with a visual system very much like ours, but situated in a world populated only by coloured lights and no surfaces. Such an organism would be able to discriminate between the colours of lights, but on my view would not exhibit colour constancy. It seems implausible to suppose, however, that such an organism would lack colour vision. In response, note that an organism with a visual system very much like ours would, ipso facto, retain the ability to achieve colour constancy, even if situated in a world in which there are no surfaces, and hence where it is not possible to discriminate differences in SSRs. On my view, then, despite being unable to exercise its capacity for colour constancy (hence colour vision) the organism nonetheless could possess the ability for colour constancy (hence colour vision).

should be able to identify plausible neural substrates for DV in humans, and to identify functionally similar substrates in all other creatures thought to possess colour constancy. These substrates moreover should be capable of sustaining perceptual representations of features of both object surfaces and illumination conditions, and these representations should be capable of driving the organism's behaviour in responding to changes in either surface or illumination properties as such. Third, DV should prove illuminating and explanatory in characterising colour constancy capacities in empirical practice. DV would be disconfirmed, to some extent, if it provided little or no help in understanding the nature of colour constancy capacities in both human and non-human cases. It should be noted, however, that DV is not intended to provide a complete characterisation of colour constancy in normal humans. The aim is rather that of providing a maximally general, all inclusive, characterisation of constancy; an account that is suited to our project of identifying a core, basic, and unifying feature of colour vision. I believe that DV is well suited to this purpose, and that the view will withstand the demands and tests of evolving empirical practice and philosophical theory.

There are several alternative characterisations of colour constancy that cannot be considered here. One particularly pertinent view, however, is the categorical view of colour constancy (CVCC) presented by Thompson ([1995], pp. 196-7),²⁴

The key to colour constancy is to be found in this joining of object identification and categorical colour perception. Rather than providing constant perceptual indicators of surface reflectance, the primary role of colour vision is probably to generate a relatively stable set of perceptual categories that can facilitate object identification and then guide behaviour accordingly... If colour constancy is an adaptation, it is better regarded not as an adaptation for object detection via the recovery of surface reflectance, but rather as an adaptation for integrating a physically heterogeneous collection of distal stimuli into a small set of visually salient equivalence classes...

²⁴ Thompson here follows Jameson & Hurvich ([1989], p. 195). See also Olkkonen et al ([2010]), Hardin ([1992]), Hatfield ([1992]), and Troost & De Weert ([1991], p. 596).

Thompson argues that the primary function of colour vision is probably to aid object recognition, a task that requires only coarse grained information as to which colour category the object belongs to. Colour constancy is then seen primarily as functioning to ensure that objects are assigned the same colour category under differing illuminants, for the purposes of object (re-)identification. This view clearly differs somewhat from DV. More worryingly, however, by tying colour constancy so closely to colour categorisation, CVCC threatens my central claim that colour vision qua constancy can be completely dissociated from CP for colour.

I offer two responses; the first defensive, the second more concessive. The first concerns CVCC's emphasis on the role of colour constancy in facilitating object recognition. Identifying an object as Bruce or as a banana presumably involves the activation of some memory representation of the individual or kind in question. Given our limited storage capacities, we can predict that much visual information will be stored in memory in simplified, discretised, and easily accessible forms. And indeed there is evidence that information about colour is represented in visual memory in categorical form.²⁵ Insofar as object identification involves the activation of memory representations of colour, then, it is plausible that these would be categorical representations of colour. The problem with CVCC is that by focusing on the functional associations between constancy and object recognition, it risks imputing features of the representations involved in colour memory onto those involved in sustaining occurrent colour constancy. These dangers are well recognised in the empirical literature. Kay and Regier ([2006], p. 53) note that 'much of the evidence for categorical "perception" of colour comes from tasks that involve memory; hence it could be that the

²⁵ See Raftapopolous ([2010]), particularly section 4.3 for discussion.

category effects stem from memory rather than perception.’²⁶ Boynton and colleagues ([1989], pp. 229-230) similarly note that ‘common experience suggests that, when colours must be remembered, categorisation is required’, and present evidence that categorical effects can be induced in simple colour discrimination tasks ‘provided that the stimuli to be compared are separated temporally.’²⁷ Even if colour constancy does function in part to aid object recognition, the categorical representations implicated in this process might better be attributed to memory than colour constancy itself.

My second response concedes that DV does offer quite a narrow perspective on the nature and role of colour constancy. As noted above, this reflects my central explanatory aim of accounting for colour constancy, hence colour vision, in all its varied guises. In this context, narrowness avoids over specificity and affords greater generality. It must be acknowledged, however, that some will think it impossible or at least misguided to divorce consideration of colour constancy from the downstream functions that it serves. Viewing constancy in this more holistic way will likely require a far richer and more complicated view than that offered by DV. I have no principled objection to such approaches, and indeed I would expect them to advance our overall understanding of perception and its integration with other cognitive capacities. My approach is simply different, and finer grained, seeking to control for as many variables as possible in accounting for this fundamental perceptual kind.

3.2. Dissociating colour vision and categorical perception for colour

Premise five states that it is possible that an organism with exactly the same discriminatory abilities – which by premise four implies the same colour vision abilities – as a normal

²⁶ See also Huttenlocher et al. ([2000]).

²⁷ In contrast, however, Franklin et al. ([2005]) present evidence for CP in visual search tasks, which minimise the role of memory.

human could completely lack CP for colour. CP is a vivid and pervasive feature of our ordinary visual experience of colour. The colour spectrum appears in experience to contain segmented regions or bands of colour corresponding to the ordinary categories red, orange, yellow, green, blue, indigo, and violet. If asked to name the colours that we see, most of us would say that we see red, orange, yellow, or shades of these categories – various reds, oranges, and yellows, and so on. It is undoubtedly central to our ordinary understanding of colour vision that it involves seeing colours in this categorically committed sense.

In what follows, CP is characterised as follows. Take three shades of colour, a , b , and c , such that the pairs a and b , and b and c , are separated by exactly the same discriminable distance, (a and c will be separated by twice that distance), and where a and b are ‘within-category’ shades – both shades are within the category green, say – and b and c is an ‘across-category’ pair – such that c lies within the category blue. Now a subject possesses CP for green just in case the within-category shades a and b appear more similar to her than the across-category shades b and c , despite the fact that they are separated by the same discriminable distance. These differential similarity effects reflect the most central feature of CP for colour, namely the banding or warping of the colour spectrum at category boundaries. The related similarity judgements with respect to triads of suitably chosen shades also provide the simplest and most precise way of assessing whether a subject possesses CP for a given category.

Assessing subjects’ differential similarity judgements in this way is an ‘implicit’ test for CP, in that it does not require the subject overtly to attend to or report on the category membership of the stimuli. Other measures of CP are available, however. A different implicit test involves assessing subjects’ reaction times on tasks in which colour category information can either aid or hinder the task’s completion. So-called ‘explicit’ tests for CP require either the comprehension or production of a colour category name, or overt attention to category

membership. Examples include asking subjects to select the ‘best’ or ‘focal instance’ of a given colour category, or actively to sort colour chips into categories. It is no doubt possible that a subject may possess CP by the lights of one test and not another. As such, we should leave open the possibility that these different tests probe different characteristics of CP for colour. Ultimately our picture of CP therefore might need to include a cluster of characteristics, including but not limited to differential similarity effects. I ignore this complication in what follows, however, as I believe that my central argument could be extended and rerun so as to accommodate a more complicated view of CP.

Non-categorical perception (NCP) with respect to a category *C* is defined as the failure to meet the above standard for CP for *C*. A subject with NCP with respect to green, then, would not perceive any differential similarities between stimuli *b* and *c* straddling the boundary between green and blue, versus the stimuli *a* and *b* that both sit within the category green. In other words, the shades *a* and *b*, and *b* and *c*, would appear equally similar to her. The notion of NCP should not seem contentious or surprising: there are obviously far more colour categories for which we are non-categorical perceivers than for which we are categorical perceivers. Extending this notion, however, we can conceive of a subject who fails to exhibit CP with respect to any superordinate colour categories. Let’s call such a global absence of CP total NCP. A subject with total NCP would experience the colours of the rainbow in a way which is quite unfamiliar. Such a subject would perceive the physical continuum of light wavelengths in a rainbow as a non-banded, non-segmented, continuum of hues. The spectrum would appear as a pure flux, altogether lacking discrete bands of colour. A subject with total NCP would not see all regions of the spectrum as chromatically homogenous. They would be able to discriminate between suitably distanced shades all the way along the spectrum, and shades that are closer together in this sequence would appear more similar than shades which are further apart. What would be lacking is the familiar

superordinate grouping of these spectral hues which is so vividly apparent in our ordinary visual experience of colour.

My argument for premise five centres on a thought experiment involving two subjects: CAT, a normal adult human, and NONCAT, who has exactly the same SSR and wavelength discrimination abilities as CAT. Given two colour stimuli a and b of differing reflectance properties, CAT can visually discriminate a from b iff NONCAT can visually discriminate a from b . By premises three and four, CAT and NONCAT are thus exactly alike in respect of their ability to achieve colour constancy, and hence in respect of their colour vision abilities. Now imagine that CAT and NONCAT are visually presented with three shades a , b , and c , such that a and b , and b and c , (not a and c), are separated by the same discriminable distance for CAT and NONCAT: both subjects can just discriminate a from b , and b from c , say.²⁸ All other contextually relevant variables such as the ambient illumination and viewing angle are held fixed. The shades a and b belong to the category red, whereas c belongs to orange. Now suppose, however, that CAT perceives b as more similar to a than to c , whereas NONCAT perceives b as just as similar to a as to c . CAT therefore meets the assumed standard for CP with respect to red, whereas NONCAT does not: CAT exhibits the requisite differential similarity effects at the boundary of red, whereas NONCAT does not.²⁹

Now consider any arbitrary colour category C , and any suitably placed triad of discriminable shades a' , b' , and c' , for which CAT exhibits the differential similarity effects required for CP with respect to C . By stipulation, the shades a' , b' , and c' , will be equally discriminable to CAT and NONCAT. But now suppose that NONCAT fails to exhibit the differential similarity effects required for CP with respect to C . NONCAT would thereby fail to exhibit CP for any of the categories for which CAT exhibits CP. Moreover, I stipulate that

²⁸ See Palmer ([1999], pp. 671-72) for discussion of just noticeable differences.

²⁹ I assume that NONCAT also fails on all other implicit or explicit tests for CP noted above.

Forthcoming in the *British Journal for the Philosophy of Science*. Please cite published version.

there are no other colour categories for which NONCAT exhibits CP, but for which CAT doesn't. NONCAT is therefore exactly similar to CAT in respect of her visual discriminatory abilities, and yet has total NCP for colour. If genuinely possible, this scenario establishes that a subject exactly like a normal human in respect of the constitutive, discriminatory, standard for colour vision could altogether lack CP for colour.

Does NONCAT present a genuine possibility? Is it possible that two subjects exactly alike in respect of their visual discriminatory abilities nonetheless could differ in respect of their CP for colour? It might be thought not, for CP is often, if not typically, characterised as a discrimination effect. In the introduction to a seminal collection of papers on this topic, for example, Harnad ([1987], p. 3) states that CP requires that 'the subject can discriminate smaller physical differences between pairs of stimuli that straddle that boundary than between pairs that are within one category or the other'. In another influential study, Bornstein and Korda ([1984], p. 208) say that CP is characterised by the 'nonmonotonic character of discriminability along [the] correlate physical dimensions' of a given perceptible feature. Taken at face value, this characterisation implies that two subjects differing in respect of CP for colour ipso facto would differ in their discriminatory abilities. This would cause trouble for our imagined scenario involving CAT and NONCAT, for CAT and NONCAT were stipulated to be exactly alike in respect of their discriminatory abilities and yet utterly different in respect of CP for colour.

Despite the quoted assertions to the contrary, the overwhelming evidence seems to be that CP for colour is not in fact a function of discrimination performance. Hardin ([1997], p. 293) comments as follows,

It is important to understand that the resemblance that connects two instances of the same colour category is not necessarily a function of the perceptual [i.e.

discriminable] distance between them. It is not hard to find three colour samples A, B, and C, [where] B is separated from A on the one side and C on the other by the same number of just-noticeable differences, and yet A and B are seen to belong to the same colour category whereas C is seen to belong to a different colour category.

Hardin is clearly not claiming that ordinary subjects do not possess CP for colour, but simply pointing out difficulties in reducing the similarity effects that are characteristic of CP to discrimination performance. Franklin and Davies ([2004], p. 352, note 2) make the same point,

[Inequality in discriminable distance] would not really be equivalent to adult categorical perception. Equivalent non-uniformities also occur within categories. Thus, quasi-categorical effects should also be found within categories. It might be thought that it is this variation in discriminability that drives category formation. Category boundaries occur at local discrimination maxima. This fits the blue-green boundary; there is a discrimination peak at about the right place. But, it is much less clear for green-yellow and yellow-orange-red.³⁰

Franklin and Davies argue that differential similarity effects are not in fact a function of discrimination, because discrimination performance does not peak at the category boundaries between green and yellow, yellow and orange, and orange and red. If differences in discrimination underlay CP, moreover, then we should expect to experience more colour categories than we in fact do, given the existence of local discrimination maxima within categories.

Further evidence for the dissociation between CP for colour and discrimination performance is presented by Roberson and colleagues ([2009]). Their study focuses on speakers of Korean, who display characteristic CP effects for three categories in the blue-

³⁰ Roberson et al. ([2009]) argue that discrimination performance also cannot explain the blue-green category boundary. See also Hanley & Roberson ([2011]).

green region, *parang* (approximately: blue), *chorok* (approximately: green), and *cheongnok* (approximately: greenish-blue), whereas English speakers display these effects for only two categories: blue and green. Despite these robust differences in CP for colour, however, discrimination thresholds across the spectrum were not significantly different for speakers of English and Korean. For most actually encountered differential similarity effects with respect to colour, then, researchers have failed to account for these effects in terms of differences in discrimination. Such evidence provides good reason to think that CP for colour is not reducible to discrimination performance. If this is correct, then we should not dismiss the possibility involving CAT and NONCAT on the grounds that their differences in CP for colour must imply differences in their discriminatory capacities.

Given the evidence cited above, how should we explain the persistence of the discriminatory characterisation of CP in the empirical literature?³¹ I believe that this characterisation persists due to a failure clearly to distinguish between notions of discriminability and similarity. In experimental contexts, the term ‘discrimination’ is typically used to describe any situation in which two sets of stimuli receive different types of response. This usage obscures the fact that two sets of stimuli might be equally visually discriminable for a subject and yet still be treated differently due to differences in their apparent similarity. To make this point concrete, consider the recent study of CP by Winawer and colleagues ([2007]). Their experiments involve an ‘ABX test’ paradigm in which subjects are presented with a target square together with two test squares, one of which is (type-)identical to the target while the other ‘distracter’ square is drawn either from the same linguistic category *F* as the target (the within-category condition) or a different linguistic category *G* (the across-category condition). Subjects are asked to report which of the two test

³¹ What’s more puzzling is that even those who claim to dissociate discrimination and CP continue to characterise CP in terms of discrimination performance. See Franklin and Davies ([2004], p. 350).

squares is the same as the target square. It is assumed that if the subject possesses CP for *F*, then she will be significantly faster at identifying the identical square in the across-category condition than the within-category condition. The logic is that if the subject possesses CP for *F*, then the test squares in the across-category condition should appear in some sense more different than the test squares in the within-category condition, which should make it easier for the subject to identify which of the test squares matches the target square in the across-category condition. The authors gloss this by saying that subjects with CP demonstrate ‘faster discrimination’ between the two fields in the across-category condition. It is crucial to note, however, that these experiments do not establish that subjects with CP for *F* show better discrimination of colours, in the sense of being able to make finer visual discriminations between colours that lie across category boundaries than between colours that lie within the same category. All that is needed to explain the difference in response is to suppose that the test fields in the across-category condition appear more dissimilar to subjects with CP for *F* than the test fields in the within-category condition.

Perhaps the strongest objection to premise five derives from the widespread practice among vision scientists of using colour category terms to describe very low level processes in the visual system. An early example is the trichromatic theory of Young and Helmholtz, which proposed that all colour experiences were the product of the combined outputs of three retinal photoreceptor types, which were labelled ‘red’, ‘green’, and ‘blue’ receptors. It is now widely acknowledged that these labels are inappropriate, however, and that these receptors are better termed ‘long’, ‘medium’, and ‘short’ (L, M, S) wavelength cones.³² The practice persists, however, in attempted physiological reductions of opponent process theory (OPT). OPT is founded on a set of observations about the phenomenal structure of our ordinary visual experience of colour. OPT posits four unique hues, which are hues that do not

³² See De Valois and De Valois ([1975], p. 107) and Gordon & Abramov ([2001], p. 103).

phenomenally appear to be a mixture of any other hue. These hues are typically labelled as unique red, unique green, unique yellow, and unique blue. All other colours phenomenally appear to be binary, in the sense that they appear to be mixtures of two hues. No colour ever appears to be a mixture of red and green, however, and likewise for yellow and blue. These pairs are therefore referred to as phenomenally opponent colours.³³ On discovery of physiologically opponent processes in animal colour vision systems in the 1950s, researchers were predictably quick to apply the categorical terminology of phenomenal OPT to these processes.³⁴ This practice remains widespread today in both scholarly research articles and textbook introductions to colour vision.

As Mollon ([1997], pp. 868-872) explains, however, the application of category terms here is once again precipitous,

We still believe today that there are chromatically antagonistic channels in the early visual system—that is, channels that draw inputs of opposite sign from different classes of cone, but these channels simply do not correspond to the phenomenologically defined channels of Hering [...] In fact, no one has found a site in the visual system where colour appears to be represented according to Opponent Colour theory—that is, a site where the cells might be held to secrete redness and greenness or yellowness and blueness... Thirty years ago we thought we understood the existence of four unique hues, hues that are phenomenally unmixed. Today this is perhaps the major unsolved problem of colour vision.

While colour category terms doubtless provide a helpful *façon de parler* in describing these opponent mechanisms, then, such attributions in no way establish that CP for colour is an inherent or fundamental aspect of colour vision.

³³ See Hardin ([1988], pp. 26, 30, 37-39, 52).

³⁴ Opponent processes were first discovered in the retinal ganglion cells of fish by MacNichol & Svaetichin ([1958]), and in the lateral geniculate nuclei of macaques by De Valois et al. ([1967]). For a summary, see Gordon & Abramov ([2001]).

A possible rejoinder is that although the application of colour category terms to physiological opponent mechanisms is inappropriate, the use of such terms in the original phenomenal form of OPT is entirely permissible. Given that phenomenal OPT captures the universal structural features of ordinary colour experience, moreover, it follows that colour vision is essentially categorical in nature. Let's flesh this rejoinder out in more detail. As noted above, phenomenal OPT is founded on the observation that all colours appear either as unique shades of red, green, yellow, and blue, or as binary complexes of these categories, such as reddish-blue and greenish-yellow, subject to the constraints of the opponent hue pairings.³⁵ Some people seemingly take these phenomenal structural features to impose unassailable constraints on the nature of colour vision. For example, Thompson ([1995], p. 9) claims that 'colour vision, whatever else it might be, is the ability to see visual qualities belonging to the phenomenal hue categories, red, green, yellow, blue'. Now presumably Thompson would agree that it is implausible that all animal colour vision involves the ability to see qualities belonging to the anthropocentric categories of red, green, yellow, and blue. Viewing these comments in light of Thompson's categorical view of colour constancy discussed above, however, it seems reasonable to conclude that he takes phenomenal OPT to imply that colour vision constitutively involves the ability visually to represent some colour categories or other.

I offer two points in response. First, as made clear at the outset, a central aim of this work is to develop an alternative to the mainstream experiential approach to theorising about colour vision. On the present constitutive approach, the fact that colour experience canonically displays some feature *F* is not taken to entail that *F* is a constitutive feature of colour vision. It seems, however, that the argument from the apparently categorical nature of

³⁵ The 'hue scaling' techniques of Jameson & Hurvich ([1959]) and Sternheim & Boynton ([1966]) indicate that the terms 'red', 'green', 'yellow', and 'blue', and combinations of these terms, are necessary and sufficient to describe all of the spectral hues.

phenomenal OPT, to the categorical nature of colour vision, employs just this type of inference. Phenomenal OPT is a partial account of the structure of colour appearance, of the topology of our ordinary conscious experience of colour. Whether or not this structure implies CP for colour, the entire point of this paper has been to challenge the assumption that any such structural feature of experience provides an incontrovertible constraint on a constitutive account of colour vision.

It might be objected that by resisting such experiential constraints, I have simply changed the subject from that commonly agreed upon by philosophers of perception. I reject this charge. My subject is colour vision, which as noted in Section 2 is agreed by all parties to be a foundational explanatory notion in this subfield. What has been changed is the method or emphasis in studying this phenomenon. My approach seeks to understand the distinctive nature of colour vision qua psychological kind, rather than to describe the features of our ordinary visual experience of colour. One is of course free to object to any or all aspects of my account. What is not acceptable, however, is to impose an experiential conception of colour vision as a precondition on the debate.

My second response is that even if one remains unconvinced by the last two paragraphs, it is in any event mistaken to think that phenomenal OPT structurally implies the presence of CP for colour. The unique hues postulated by OPT are typically labelled ‘unique red’, ‘unique green’, ‘unique blue’, and ‘unique yellow’. This might suggest a straightforward relationship between visually perceiving the unique hues and seeing the colour categories red, green, blue, and yellow. This thought is bolstered by empirical evidence that subjects who possess CP for these categories typically locate their foci or paradigmatic examples at or very close to the corresponding unique hues.³⁶ Despite the undoubted correlations, however, there

³⁶ McDaniel ([1972]) first proposed the link between colour category foci and the unique hues. See Wooten & Miller ([1997], p. 83). MacLaurey ([1997], p. 263) discusses some problems with this proposal. Philipona &

is no constitutive connection between the traditional phenomenally opponent colour space and CP for colour. Actual empirical cases suffice to make the point. The aforementioned study by Winawer and colleagues ([2007]) indicates that Russian subjects possess CP for two categories in the bluish region, roughly corresponding to light blue and dark blue. In accordance with OPT, we can assume that Russian subjects perceive a single unique hue in the bluish region. This unique hue could not possibly form the focal point for the category blue for these subjects, for the simple reason that these subjects do not possess CP for blue, but rather for light blue and dark blue. Similarly, Roberson and colleagues ([2009]) found that Korean subjects possess CP for three categories, *chorok*, *cheongnok* and *parang*, in the blue-green region. In accordance with OPT, we can assume that Korean subjects perceive two unique hues in this region: so-called ‘unique blue’ and ‘unique green’. Once again, however, these hues could not possibly form the focal points for the colour categories blue or green for these subjects, for the simple reason that Korean subjects do not possess CP for blue or green. There is no straightforward implication, then, from having experiences of colour that can be characterised by phenomenal OPT, to possessing CP for the colour categories blue, green, and so on.

Extending this point, we can see that phenomenal OPT does not imply the possession of CP for any colour categories whatsoever. The above cases all involve subjects who possess CP for more colour categories than ordinary English speakers. We can easily imagine cases in which subjects have CP for fewer colour categories than English speakers, but who still perceive the four unique hues posited by OPT. A moderate case would be a subject who possessed CP for a category that spanned both blue and green, and hence included both the ‘unique green’ and ‘unique blue’ hues. A more extreme case would be a subject like

O’Regan ([2006]) provide an ecological argument for the origin of the unique hues, focusing on certain illumination-invariant regularities in reflectance properties.

NONCAT who lacked CP for any colour categories whatsoever, and yet still had experiences as of the four unique hues. These points undermine any constitutive connection between phenomenal OPT and CP for colour. By the same token, these cases demonstrate how misleading it is to label the unique hues postulated by OPT with the category terms ‘red’, ‘green’, ‘yellow’, and ‘blue’. This response nullifies the biggest threat to premise five, and thus clears the way for my conclusion that colour vision does not constitutively involve the ability to see colours in the natural, categorically committed, sense.

The reader at this point might remain unconvinced. Surely, one might object, if a normal perceiver perceives unique blue and unique red and also perceives non-unique blues and non-unique reds, then she ipso facto perceives colour categories. My response is simply to reiterate the adopted characterisation of CP for colour, which requires the presence of differential similarity effects between shades of colour at category boundaries. According to this standard, even if NONCAT perceives shades that English speakers would call ‘unique red’ and ‘non-unique red’, then so long as she does not exhibit the canonical differential similarity effects between these shades, she does not possess CP for red.

4. Whorf and the View from Cognitive Neuropsychology

While colour CP has not featured prominently in philosophical discussions about colour, the psychological origin of this ability has been a matter of considerable debate in cognitive psychology. The argument of the previous Section introduced evidence for cross-linguistic variations in CP, as in the examples of the categorisations made by Russian and Korean speakers. These results are part of a recent revival of relativist or Whorfian views of perceptual categorisation.³⁷ This marks a significant departure from the Universalist

³⁷ For a summary, see Kay & Regier ([2006]).

orthodoxy of the last forty years, on which the colour categories apparent in our ordinary visual experience are deemed universal, presumably very low-level, features of colour vision systems. Universalism has undoubtedly permeated philosophy to some degree, perhaps partly explaining the widespread assumption that the ability to see colour categories such as red and green is somehow inherent to, or part of the nature of, colour vision.³⁸ In its strongest form, the Whorfian view holds that all of our perceptual categories are determined (in some sense) without constraint by the language that we speak. In Whorf's words ([1940], p. 213),

The categories and types that we isolate from the world of phenomena we do not find there because they stare every observer in the face. On the contrary the world is presented in a kaleidoscopic flux of impressions which have to be organised in our minds. This means, largely, by the linguistic system in our minds.

Nobody today would endorse such an extreme view.³⁹ Nevertheless, cross-cultural studies of the sort carried out by Winawer and colleagues ([2007]) have been taken to support a weaker neo-Whorfian thesis,

(WT) Some structural differences between colour language systems will be paralleled by differences in the colour categories apparent or represented in the visual experience of the native speakers of these languages.

I now introduce some fascinating cognitive neuropsychological cases which have been cited as further support for the neo-Whorfian view. Such cases demonstrate that the possibility of a total dissociation between core colour vision abilities and CP for colour, on which my argument rests, is not only coherent, but also not nearly as distant as one might think. I should

³⁸ The Universalist view originates in the seminal cross-cultural study of Berlin & Kay ([1969]). Arguably the most widely read and influential philosophical introduction to the science of colour vision, Hardin's *Colour for Philosophers*, presents the standard Universalist line at ([1988], pp. 156-169).

³⁹ Compare Quine ([1948], p. 11).

stress, however, that my central argument is not at all dependent on the truth of neo-Whorfianism, which is just as well given the highly contentious nature of the view.⁴⁰ Reflecting on the neo-Whorfian view is simply helpful in opening our minds to certain possibilities as to how things might have been with respect to our colour categorisation abilities.

Some studies in cognitive neuropsychology have addressed a rare condition known as visual colour anomia or optic aphasia for colours. Aphasias are linguistic impairments typically resulting from a head injury or stroke. Anomia is a type of aphasia involving a specific impairment in the production of names or verbal labels. Optic aphasia for colours is partly characterised by impairment in the naming of colours. Unlike colour aphasia, which is a purely verbal deficit in producing or comprehending colour terms, optic aphasia for colours is a visuo-verbal deficit which also results in impairments in the subject's ability visually to categorise colours. The earliest reports of such cases appear in work by the German neurologists Sittig ([1921]), Goldstein and Gelb ([1918]), who described it as an 'impairment of the categorical attitude' towards colour, and Lange ([1936], p. 88), who says that,

The patients do not behave conceptually but in terms of concrete reality[...] The patients have no principle of classification in colour sorting, but depend on the experience of coherence between patterns and the other colours.

⁴⁰ Some of the results taken to motivate a neo-Whorfian view have been called into question. For example, Witzel & Gegenfurtner ([2011]) report that attempts to replicate Gilbert et al.'s ([2006]) finding that CP is lateralised to the right visual field have been inconsistent. Franklin & Davies ([2004]) also present evidence for colour categorisation in pre-linguistic infants, which is hard to explain on a thorough-going Whorfian view.

More recently, Beauvois and Saillant ([1985]) distinguished optic aphasia for colours from the more general linguistic deficits associated with colour aphasia, and also from colour-specific visual agnosia.

Beauvois and Saillant ([1985]) describe the case of MP, who is diagnosed as having optic aphasia for colours. MP's visual and linguistic abilities with respect to colour were assessed via purely verbal, purely visual, and combined visuo-verbal tasks. MP performed within the normal range on tasks that required purely verbal processing of colour information. The purely visual tasks included colour matching tests, in which subjects are given two wool skeins and asked to decide if they are identical or not, and standard pseudo-isochromatic plates for colour discrimination. Once again MP's performance on such tasks was within the normal range. In contrast, MP's performance on visuo-verbal tasks was extremely impaired. In one task, MP was asked to produce a verbal colour label in response to a visually presented colour sample, or to point to a colour sample given a verbal request. MP's errors here were gross and difficult to understand: she labelled a bright red sample as 'light yellow', pointed to navy blue when asked to point to orange, and pointed to pale blue when asked to point to the colour of parsley. MP was also assessed on the Gelb-Goldstein colour sorting test, which requires the subject to 'select a skein of wool he likes and to pick out all the skeins which he believes can be grouped together with the chosen one' ([1985], p. 15). Once again, MP's performance was highly unusual ([1985], p. 15),

[S]he started with a pale grey and put it with the other grey, the white and the dark wools; then with them she put, in the following order: A pale pink, a pale yellow, a brown; she continued by adding all the pale pink and brown wools, and she finished by putting all the wools in the same category... On part 4 of the test, in which she was asked to select just the red wools, she picked up all the wools except for 10 (white, black, grey, one brown, four grey and two green); she seemed to select them without any apparent logic in order (e.g., she picked out a green wool just after a pink one, or a red just after a green).

It is significant to note that both of these visuo-verbal tasks are paradigmatic explicit tests for colour CP, which I mentioned in Section 3.2. MP's behaviour thus presents an intriguing dissociation between purely visual discriminatory abilities with respect to colour, on the one hand, and performance on explicit tests for colour CP, on the other. Despite their extreme problems with explicit colour categorisation tasks, however, patients with optic aphasia for colour often perform within the normal range on implicit categorisation tasks, including the canonical test for differential similarity judgements across category boundaries.⁴¹ By the lights of the assumed standard for CP in this paper, then, these subjects class as possessing CP for colour.

As Roberson and colleagues ([1999]) point out, a probable cause of this unusual categorising behaviour is the subject's linguistic deficit. Roberson and colleagues thus take such cases as evidence for the neo-Whorfian view of colour categorisation. As noted above, the success or failure of such empirical arguments for neo-Whorfianism is not my concern. The relevance to the present argument is that these cases provide a significant validation of the pivotal dissociative possibility discussed in the previous Section involving total NCP for colour. Although MP meets the official standard for CP assumed in this paper, her radically impaired performance on explicit categorisation tasks suggests that she lacks just about every other ability usually associated with CP for colour. Such subjects thus come extremely close to the sort of dissociation between constitutive colour vision abilities and CP envisaged in the case of NONCAT. It is certainly no stretch to imagine a subject just like MP also failing implicit tests for CP, which would suffice to establish the relevant possibility. Despite the

⁴¹ See the discussion of the patient LEW in Roberson et al. ([1999]). It is not unusual for patients with visual deficits as measured by performance on explicit tasks to perform relatively normally on implicit tasks. Nijboer ([2007], pp. 144-145) notes related findings in blindsight, object agnosia, and prosopagnosia.

apparent strangeness, then, perhaps the scenario involving NONCAT is not as distant as one initially might think.

5. Conclusion

I have motivated and implemented a constitutive approach to understanding colour vision. The constitutive approach seeks to understand colour vision qua psychological kind, as opposed to a primarily phenomenological or experiential phenomenon. I proposed colour constancy as a core constitutive condition on colour vision. Constancy in turn was explicated via DV as a discriminatory, yet fully representational, capacity. I then argued that the possession of CP for colour, a pervasive and vivid feature of ordinary visual experience, is not implied by the possession of these constitutive discriminatory abilities. In sum, colour vision does not by its nature confer the ability to see colours in a natural, categorically committed, sense. This claim was further motivated by evidence of closely related dissociations in cognitive neuropsychology. As is often the case, the unexpected actual extends our knowledge as to what is possible. Such cases confirm that our ordinary experience of colour possesses a latent complexity that is obscured by ordinary experiential, introspective, approaches to understanding colour vision.

Many issues deserving of extended discussion inevitably have been omitted or passed over too briefly. One issue of outstanding importance concerns the implications of the constitutive approach for colour ontology. If my argument is sound, then the ability visually to represent categorical colour properties such as red and green is not part of the constitutive nature of our colour vision abilities. Somewhat paradoxically, this suggests that colour ontology similarly will be free of the properties that we ordinarily describe simply as the

Forthcoming in the *British Journal for the Philosophy of Science*. Please cite published version.

colours.⁴² Further discussion of these consequences, however, will have to await another occasion.

Acknowledgements

For extremely helpful comments on this paper (and its predecessors) I would like to thank Alex Byrne, Mazviita Chirimuuta, John Hawthorne, Mark Kalderon, John Morrison, Scott Sturgeon, and Timothy Williamson; an audience at the Oxford Philosophy of Mind Work in Progress group; and two anonymous referees for this journal.

Oxford Uehiro Centre for Practical Ethics

Suite 8, Littlegate House

St Ebbes Street, Oxford OX1 1PT

will.davies@philosophy.ox.ac.uk

References

- Akins, K. [2001]: 'More Than Mere Colouring: A Dialog Between Philosophy and Neuroscience on the Nature of Spectral Vision', in S. Fitzpatrick and J. T. Breur, (eds), *Carving our Destiny*, Joseph Henry Press: Washington, D.C., pp. 77-116.
- Akins, K. & Hahn, M. [2000]: 'The Peculiarity of Colour', in Steven Davis (ed.), *Colour Perception: Philosophical, Psychological, Artistic and Computational Perspectives*, Vancouver Studies in Cognitive Science, Volume IX, pp. 215-47.
- Akins, K. & Hahn, M. [2014]: 'More than Mere Colouring: The Role of Spectral Information in Human Vision', *British Journal of Philosophy of Science*, **65(1)**, pp. 125-71.
- Allen, K. [2009]: 'Inter-species variation in colour perception', *Philosophical Studies*, **142**: 197-220.

⁴² For a related view, see Smart ([1975], p. 7).

Forthcoming in the *British Journal for the Philosophy of Science*. Please cite published version.

Arend, L. & Reeves, A. [1986]: 'Simultaneous colour constancy', *Journal of the Optical Society of America A*, **3(10)**, pp. 1743–51.

Armstrong, D. [1978]: *Universals and Scientific Realism: A Theory of Universals Vol. II*, Cambridge University Press.

Armstrong, D. [1987]: 'Smart and the secondary qualities', in Byrne and Hilbert [1997a], pp. 33–46.

Balkenius, A. & Kelber, A. [2004]: 'Colour constancy in diurnal and nocturnal hawkmoths', *The Journal of Experimental Biology*, **207**, pp.3307-16.

Beauvois, M. F. & Saillant, B. [1985]: 'Optic aphasia for colours and colour agnosia: A distinction between visual and visuo-verbal impairments in the processing of colours', *Cognitive Neuropsychology*, **2(1)**, pp.1-48.

Berlin, B., Kay, P., [1969]: *Basic Colour Terms: Their Universality and Evolution*, Berkeley, CA: University of California Press.

Boghossian, P., A., & Velleman, D., J. [1989]: 'Colour as a secondary quality', in Byrne & Hilbert [1997a] pp.81–103.

Boghossian, P., A., & Velleman, D., J. [1991]: 'Physicalist Theories of Colour', in Byrne and Hilbert [1997a] pp. 105-36.

Bornstein, M. H. & Korda, N. O. [1984]: 'Discrimination and matching within and between hues measured by reaction times: some implications for categorical perception and levels of information processing', *Psychological Research*, **46**, pp, 207-22.

Boynton, R. M., Fargo, L., Olson, C., Smallman, H. [1989]: 'Category effects in colour memory', *Colour Research and Application*, **14(5)**, pp. 229-34.

Burge, T. [2010]: *Origins of Objectivity*, New York: Oxford University Press

Byrne, A., & Hilbert, D., (eds) [1997a]: *Readings on Colour Vol. 1: The Philosophy of Colour*, Cambridge, MA: MIT Press.

Byrne, A., & Hilbert, D., (eds) [1997b]: *Readings on Colour Vol. 2: The Science of Colour*, Cambridge, MA: MIT Press.

Byrne, A. and Hilbert, D. [2003]: 'Colour realism and colour science', *Behavioural and Brain Sciences*, **26**, pp. 3–64.

Chirimuuta, M. [2008]: 'Reflectance realism and colour constancy: What would count as scientific evidence for Hilbert's ontology of colour?', *Australasian Journal of Philosophy*, **86(4)**, pp. 563–82.

Cohen, J. [2008]: 'Colour constancy as counterfactual', *Australasian Journal of Philosophy*, **86(1)**, pp.61-92.

Cohen, J. [2009]: *The Red and the Real: An Essay on Colour Ontology*, New York: Oxford University Press.

Craven, J. & Foster, D. H. [1992]: 'An operational approach to colour constancy', *Vision Research*, **32(7)**, pp. 1359-66.

Davies, W. [Forthcoming]: 'Colour constancy, illumination, and matching', *Philosophy of Science*.

Davies, W. [Unpublished]: *Essays on the Perception, Representation, and Categorisation of Colour*, unpublished DPhil thesis, University of Oxford, <http://ora.ox.ac.uk/objects/uuid:88c473a0-9717-4ec3-9ba7-88e130f33066>

Delk, J. L., & Fillenbaum, S. [1965]: 'Differences in perceived colour as a function of characteristic colour', *American Journal of Psychology*, **78**, pp. 290-93.

DeValois, R., L., & DeValois K., K. [1975]: 'Neural Coding of Colour', in Byrne and Hilbert [1997b] pp. 93-140.

DeValois, R. L, Abramov, I., & Mead, W. R. [1967]: 'Single cell analysis of wavelength discrimination at the lateral geniculate nucleus in the macaque', *Journal of Neurophysiology*, **30**, pp. 415-33.

Dörr, S., Neumeier, C. [2000]: 'Colour constancy in goldfish: the limits', *Journal of Comparative Physiology*, **186**, pp885-96

Foster, D. H., Amano, K., & Nascimento, S. M. C. [2001]: 'Colour constancy from temporal cues: better matches with less variability under fast illuminant changes', *Vision Research*, **41**, pp. 285-93.

Foster, D. H., Craven, B. J., & Sale, E. R. H. [1992]: 'Immediate Colour Constancy', *Ophthalmic and Physiological Optics*, **12**, pp. 157-60.

Foster, D. H., & Nascimento, S. M. C. [1994]: 'Relational colour constancy from invariant cone-excitation ratios', *Proceedings of the Royal Society of London B: Biological Sciences*, **257**, pp. 115–21.

Franklin, A. & Davies, I. R. L. [2004]: 'New Evidence for Infant Colour Categories', *British Journal of Developmental Psychology*, **22**, pp. 349-77.

Franklin, A., Pilling, M., & Davies, I. R. L. [2005]: 'The nature of infant colour categorization: evidence from eye movements on a target detection task', *Journal of Experimental Child Psychology*, **91**, pp. 227–48.

Gert, W. [2010]: 'Colour Constancy, Complexity, and Counterfactual', *Nous*, **44(4)**, pp. 669-90.

Gilbert, A. L., Regier, T., Kay, P., & Ivry, R. B. [2006]: 'Whorf hypothesis is supported in the right visual field but not the left', *Proceedings of the National Academy of Science*, **103(2)**, pp. 489-94.

Goldstein, K. & Gelb, A. [1918]: 'Psychologische Analysen hirnpathologischer Falle auf Grund von Untersuchungen Hirnverletzer', *Zeitschrift für die gesamte Neurologie und Psychiatrie*, **41**, pp. 1–142.

Gordon, J. and Abramov, I. [2001]: 'Colour Vision', in E. B. Goldstein (ed.), *The Blackwell Handbook of Perception*, Oxford: Blackwell, pp. 92-127.

Hanley, J. R. & Roberson, D. [2011]: 'Categorical perception effects reflect differences in typicality on within-category trials', *Psychonomic Bulletin & Review*, **18(2)**, pp. 355-63.

Hardin, C. L. [1988]: *Colour for Philosophers: Unweaving the Rainbow*, Indianapolis, MA: Hackett.

Hardin, C., L. [1997]: 'Colour Quality and Colour Structure', in Byrne & Hilbert [1997a] pp. 289-302.

Forthcoming in the *British Journal for the Philosophy of Science*. Please cite published version.

Hardin, C. L., & Maffi, L. (eds) [1997]: *Colour Categories in Thought and Language*, Cambridge University Press.

Harnad, S. [1987]: *Categorical perception: The Groundwork of Cognition*, Cambridge University Press.

Hatfield, G. [1992]: 'Colour perception and neural encoding: does metameric matching entail a loss of information?', *PSA 1192*, **1**, pp. 492-504.

Hilbert, D., R. [1992]: 'What is colour vision?', *Philosophical Studies*, **68**, pp. 351-70.

Hilbert, D., R. [2005]: 'Colour constancy and the complexity of colour', *Philosophical Topics*, **33(1)**, pp. 141-58.

Huttenlocher, J., Hedges, L. V., & Vevea, J. L. [2000]: 'Why do categories affect stimulus judgment?', *Journal of Experimental Psychology: General*, **129**, pp. 220-41.

Jackson, F., & Pargetter, R. [1997]: 'An Objectivist's Guide to Subjectivism About Colour', in Byrne & Hilbert [1997a] pp. 67-79.

Jameson, K., & Hurvich, L. M. [1959]: 'Perceived colour and its dependence on focal, surrounding, and preceding stimulus variables', *Journal of the Optical Society of America*, **49**, p. 890.

Jameson, D. and Hurvich, L. M. [1989]: 'Essay Concerning Colour Constancy', in Byrne and Hilbert [1997b] pp. 177-98.

Kalderon, M. [2007]: 'Colour Pluralism', *Philosophical Review*, **116(4)**, pp. 563-602.

Kay, P. & Regier, T. [2006]: 'Language, thought, and colour: recent developments', *TRENDS in Cognitive Science*, **10(2)**, pp. 51-4.

Kelber, A. & Osorio, D. [2010]: 'From spectral information to animal colour vision: experiments and concepts', *Proceedings of the Royal Society B*, **277**, pp. 1617-25

Kinoshita, M. and Arikawa, K. [2000]: 'Colour constancy of the swallowtail butterfly *Papilio xuthus*', *Journal of Experimental Biology*, **203**, pp. 3521-30.

Lange, J., [1936]: 'Agnosia and apraxia', in J. W. Brown (ed.), *Agnosia and Apraxia: Selected Papers of Liepmann, Lange and Poetzl (Institute for Research in Behavioural Neuroscience)*, New York: Psychology Press.

McDaniel, C. K. [1972]: *Hue perception and hue naming*, unpublished BA thesis, Harvard University.

McGinn, C. [1996]: 'Another look at colour', *The Journal of Philosophy*, **93(11)**, pp. 537-53.

MacLaurey, R. [1997]: 'Skewing and darkening: dynamics of the *cool* category', in Hardin & Maffi [1997], pp. 261-82.

MacNichol, E. F., & Svaetichin, G. [1958]: 'Electrical responses from the isolated retinas of fishes', *American Journal of Ophthalmology*, **46(3)**, p. 26.

MacPherson, F. [2012]: 'Cognitive Penetration of Colour Experience: Rethinking the Issue in Light of an Indirect Mechanism', *Philosophy and Phenomenological Research*, **84(1)**, pp. 24-62.

Matthen, M. [1999]: 'The Disunity of Colour', *Philosophical Review*, **108(1)**, pp. 47-84.

Forthcoming in the *British Journal for the Philosophy of Science*. Please cite published version.

- Matthen, M. [2005]: *Seeing, Doing, and Knowing*, New York: Oxford University Press.
- Mollon, J. [1997]: ‘“...On the Basis of Velocity Clues Alone”: Some Perceptual Themes 1946-1996’, *The Quarterly Journal of experimental Psychology*, **50A(4)**, pp. 859-78.
- Nijboer, T. [2007]: ‘Neuropsychology of Colour Vision: Studies in patients with acquired brain damage, healthy participants, and cases with developmental disorders’, PhD Thesis, University of Utrecht.
- Neumeyer, C. [1981]: ‘Chromatic adaptation in the honeybee: successive color contrast and color constancy’, *Journal of Comparative Physiology*, **144**, pp. 543-53
- Neumeyer, C. [1998]: ‘Comparative aspects of colour constancy’, in Walsh & Kulikowski [1998], pp. 323-51.
- Neumeyer, C., Dörr, S., Fritsch, J., Kardelky, C. [2002]: ‘Colour constancy in goldfish and man: influence of surround size and lightness’, *Perception*, **31**, pp. 171-87
- Olkkonen, M., Witzel, C., Hansen, T., Gegenfurtner, K. R. [2010]: ‘Categorical colour constancy for real surfaces’, *Journal of Vision*, **10(9)**, pp. 1-22.
- Palmer, S. E. [1999]: *Vision Science: Photons to Phenomenology*, Cambridge, MA: MIT.
- Palmer, S. E., Brooks, J., Nelson, R. [2003]: ‘When does grouping happen?’, *Acta Psychologica*, **114**, pp. 311-30.
- Philipona, D.L., & O'Regan, J.K. [2006]: ‘Colour naming, unique hues, and hue cancellation predicted from singularities in reflection properties’, *Visual Neuroscience*, **23(3-4)**, pp. 331-39.
- Quine, W. V. O. [1948]: ‘On What There Is’, in J. Kim & E. Sosa (eds), *Metaphysics: An Anthology*, Oxford: Blackwell Publishers, pp. 4-12.
- Roberson, D., Davidoff, J. and Braisby, N. [1999]: ‘Similarity and categorization: neuropsychological evidence for a dissociation in explicit categorization tasks’. *Cognition*, **71**, pp. 1–42.
- Roberson, D., Hanley, J.R., & Pak, H.S. [2009]: ‘Thresholds for colour discrimination in English and Korean speakers’, *Cognition*, **112(3)**, pp. 482-87.
- Shea, N. [2012]: ‘Methodological Encounters with the Phenomenal Kind’, *Philosophy and Phenomenological Research*, **84(2)**, pp. 307-44.
- Sittig, O., [1921]: ‘Störungen im Verhalten gegenüber Farben bei Aphasischen’, *Monatsschrift fuer Psychiatrie und Neurologie*, **49**, pp. 63–8.
- Smart, J.J.C. [1975]: ‘On Some Criticisms of a Physicalist Theory of Colours’, in Byrne and Hilbert [1997a].
- Smith, A. D. [2002]: *The Problem of Perception*, Cambridge, MA: Harvard University Press.
- Sternheim, C.E., and Boynton, R. M. [1966]: ‘Uniqueness of perceived hues investigated with a continuous judgemental technique’, *Journal of Experimental Psychology*, Vol 72(5), pp770-6.
- Strawson, P. F. [1979]: ‘Perception and its objects’, in G. F. MacDonald (ed.), *Perception and Identity*, London: Macmillan, pp. 41-60.

Forthcoming in the *British Journal for the Philosophy of Science*. Please cite published version.

Thompson, E. [1995]: *Colour Vision: A Study in Cognitive Science and the Philosophy of Perception*, London and New York: Routledge.

Thompson, E., Palacios, A., Varela, F. J. [1998]: 'Ways of Colouring: Comparative Colour Vision as a Case Study for Cognitive Science', in A. Nöe & E. Thompson (eds), *Vision and Mind: Selected Readings in the Philosophy of Perception*, Cambridge, MA: MIT Press, pp. 351-418.

Troost, J. M., & De Weert, C. M. M. [1991]: 'Naming versus matching in colour constancy', *Perception and Psychophysics*, **50(6)**, pp. 591-602.

Tye, M. [2000]: *Colour, Consciousness, and Content*, Cambridge, MA: MIT Press.

Walsh, V., Kulikowski, J. (eds.) [1998]: *Perceptual Constancy: Why Things Look As They Do*, Cambridge: Cambridge University Press.

Werner, A., Menzel, R. and Wehrhahn, C. [1988]: 'Colour constancy in the honeybee', *Journal of Neuroscience*, **8**, pp. 156-159.

Whorf, B. L. [1940]: 'Science and Linguistics', *Technology Review*, **42(6)**, pp. 229-31, 247-8.

Williamson, T. [1990]: *Identity and Discrimination*, Oxford: Blackwell Publishing.

Winawer, J., Witthoft, N., Frank, M., Wu, L., Wade, A., Boroditsky, L. [2007]: 'The Russian Blues reveal effects of language on colour discrimination', *Proceedings of the National Academy of Science*, **104(19)**, pp. 7780-85.

Witzel, C. & Gegenfurtner, K. R. [2011]: 'Is there a lateralised category effect for colour?', *Journal of Vision*, **11(16)**, pp. 1-25.

Wooten, B., & Miller, D. [1997]: 'The psychophysics of colour', in Hardin & Maffi [1998], pp. 59-88.

Wright, W. [2013]: 'Colour Constancy Reconsidered', *Acta Analytica*, **28**, pp. 435-55.