Hypothetical Identities and Chimerical Reductions

Introduction

Hypothetical identities are the newest arrival on the scene of reductionist philosophy of mind and consciousness. Paul Churchland's (2007) most recent version of the reduction of color qualia follows this strategy. McCauley and Bechtel's (2001) heuristic identity theory is a general account applicable to all areas of cognitive neuroscience. But are hypothetical identities a needed addition to the epistemology of naturalistic ontology? In this paper, I argue that the answer depends on a clear picture of how empirical methods of testing relate to different identity statement types. I will show that both McCauley and Bechtel's and Churchland's versions suffer from shortcomings in predictive power, falsifiability. This claim directly contradicts Churchland's argument about the power of the opponent process color theory to generate novel predictions, qualia. I will argue, first, that some of Churchland's predictions have already been falsified in experiments and, second, that his hypothetical isomorphism-based psychoneural identity statements are not tested at all by "chimerical" novel colors but function as an unfalsifiable axiom. As an illustration of the general thesis, I will also argue that to test common isomorphism-based identity statements about qualia and their mechanisms, novel structural predictions are needed and for both reductionist epistemological and ontological conclusions.

I. Hypothetical Identities

Ontological reductionism has a complicated relationship to scientific practice. The same is true of epistemological reduction. Unificationist criteria are an arm's length from scientific practice. As a result, reductionism has been largely a matter of meta-level analyses of science. This situation has changed. Naturalistically inclined philosophers locate reductionism in scientific practice. Once part of methodological practice, reductions become one more "method

of hypothesis," and identity-statements "hypothetical identities." Let us look at examples of the proffered methodology for such identifications.

According to McCauley and Bechtel's (ibid, 753) "heuristic identity theory," "HIT," identity-statements are "not the conclusions of scientific research but the premises." For them, psycho-neural identity-statements are so pervasive in the inter-disciplinary practices of cognitive neuroscience that they should be seen as heuristics. It is such heuristics that "enable scientists working at one analytical level to exploit the conceptual, theoretical, methodological and evidential resources available at another" (ibid). Consequently, they lead to intra-level modification and also of the key concepts used to describe phenomena at different levels. Given their broad use, hypothetical identities are heuristics for *discovery* in multi-level research areas.

McCauley and Bechtel make a good case for the role of heuristic identities in "co-evolutionary" scientific change at both the functional and neural levels of vision science. They also attribute a rough pattern to such change: heuristic identities drive change in "conceptions of the pertinent processes and structures in a reciprocal process of mutual fine-tuning" (ibid, 754); they "reliably" result in "more detailed hypotheses" (ibid, 737). Although McCauley and Bechtel underscore the role of heuristic identities in discovery, they do think these can also be justified. This occurs the same way as the "justification of any other hypothesis" (ibid). Although they never clarify a model of justification, hypothetical identities' success is concerned with "refining theories at both of the levels engaged" and precisely because they generate and make available new evidence (ibid, 754).

Schouten and de Jong (2001) call for a clarification between the discovery function of hypothetical identities and their methodology. For them, rightly, "not every identification is as good as any other" (ibid, 802). The need for a methodology is reinforced by HIT's potential for "wild proliferation" evident in their inter-disciplinary area of study, genetics and its "gene of the week" phenomenon (ibid, 802-3).[1] To put it simply, we need to distinguish between mere use and proper use or science and self-corrective, rational science. For methodological purposes, Schouten and de Jong underscore "failures that identifications are capable of bringing to the fore" (ibid, 802). They emphasize then conditions of falsification for the use and justification of hypothetical identities. For Schouten and de Jong, only this can counter proliferation and

[1] The association between the proliferation of hypotheses and the anarchist, "anything goes" methodology of Feyerabend might also be a useful general reminder.

possibly turn hypothetical identities to Wimsatt's (1984, 498) "probes of unlimited sensitivity and depth in pinpointing sources of explanatory failure."

It might be objected that McCauley and Bechtel's HIT must involve falsification since, for them, identifications are justified like "any other hypothesis." Yet, a history of proliferation in identifications is also true of cognitive neuroscience and its "neuron-code of the week" and "brain area of the week" hyperbole. Minimally, methods of HIT and their scientific application are at odds. A likely reason is the conceptual connection between the degree of falsifiability of a hypothesis and its clarity and precision. This applies also to hypothetical identities. Open-ended identities are more likely to be unfalsifiable. McCauley and Bechtel's concept of identity is open-ended: identification of functions with mechanism. Without pre-study constraints on the nature of a successful neural identification or "implementation" of a function, a methodology of falsification is unclear and the "reciprocal process of mutual fine-tuning" ad hoc. In other words, without testing specific forms of identity, research into hypothetical type-identities threatens to become a matter of after-the-fact, ad hoc accommodation. HIT generates more science but maybe not method-governed science.[2] For HIT to incorporate justification, the actual nature of hypothesized identities must be such that one, they can be falsified and, two, their falsification can guide further study.

Paul Churchland's (2007) hypothetical identities suffer from none of the ambiguities of HIT. The identity statement itself is an isomorphism and the justification of the hypothesis occurs through predictions. Churchland argues for an identity between color qualia and neuron responses by using a reductive color theory including a hypothetical identity to derive novel predictions. In short, he intends to provide "an empirical test of the identity theory itself (ibid, 162). Analyzing Churchland's argument is important for advancing the methodology of hypothetical identities because it allegedly rests on verified novel predictions.[3] To assess Churchland's argument, we must sketch the theory of color vision used in deriving predictions

[2] Consider that even the pursuit of "coferential" forms of psycho-neural identity can generate science although as hypotheses these are virtually unfalsifiable if it is not specified how co-referentiality should be manifested in the evidentiary realms of the relevant sciences.

[3] It might be also be seen as a natural end-point for McCauley and Bechtels' developmental HIT once the co-evolutionary "fine-tuning" has run its course and bottomed-out in the way it may have according to reductionists in highly developed areas of sensory neuroscience such as color.

including its inter-level models, old evidence for it, and the novel predictions through which their truth or falsity is assessed.

II Hypothetical Identity of Color Qualia and Neuron Responses

Churchland's reductionist argument is based on the opponency theory of chromatic information processing. Churchland refers to it as the "Standard Model" ("SM" henceforth) of how color is processed and represented "in the brain" (ibid, 162). SM is a neural model, an implementation of a functional or "psychophysical" model of color processing. It includes a neural representation of color. To see how, we must first analyze the functional model of hypothetical color channels.

The functional model of SM has two aspects. One is a model of color appearance or phenomenology. Like any model it has elements and relations. The elements are "unique" hue sensations: red, green, blue and yellow (together with the achromatic color sensations white and black). The relations include combinations or "binary" hues such as reddish-yellow oranges and unique hues varying in saturation and/or brightness. "Opponency" is the key relation. The unitary hues of the red-green and blue-yellow pairs are never both perceivable in a light. Opponency is also a dynamical relation: red and green (and blue and yellow) can be mixed in a manner to make the light appear white, achromatic. This dynamical relation is used to measure the strength of the hue responses to light in the so called "color cancellation experiment." Subjects "cancel out" specific hues from light stimuli throughout the simple spectrum with cancellation primaries, the unique hues, in terms of the relationships of opponency. For example, from a bluish-green stimulus the subject will "cancel out" the greenish appearance by mixing a "unique" red light. This results in desaturated blue. The intensity of the unique red stimulus required to cancel out green determines the (relative) strength of response (of green) in the red-green channel at that wavelength. The same can be done for the blue in the mixture by mixing yellow to it.

In total, the functional model of SM consists of two independent opponent hue channels, red-green and a blue-yellow (and an achromatic non-opponent white-black channel), together with their respective "strengths of response" as a function of wavelength. And when strength of

response is equated with sensitivity to light, SM specifies two "chromatic response curves" for the hue-channels.

Let us turn to the neural side of SM. A neuroreduction requires knowledge of neurons' sensitivities to light. This is acquired through single cell recordings that measure neurons' levels of excitation to light. The "fit" between the sensitivity functions of the neural and functional models is the essence of the reductionist SM. This "isomorphism" requires a neural color code, the representation of hues in neurons. According to SM, neural responses are also opponent. Opponency refers to a dichotomous classification of relative neural excitation. More specifically, neuron responses are inhibitory when below the spontaneous discharge rate and excitatory when above it. Inhibition and excitation are conceptualized as "opponent," similar to the hues. Representing neural and perceptual opponency identically, by opposite signs, makes possible an isomorphic representation of the two data models, the sensitivity curves for the two functional opponent channels and the statistically processed average sensitivities of the neurons.[4] Hardin (1993, 54) expressed the logic behind the use of the isomorphism-based coding assumption well in stating that "some of the chromatically responsive cells show opponent-response patterns that fit psychophysical inferred-response patterns beautifully."

Let us now turn to evidence. The neural side of SM was created by accommodating "old" psychological data from the color cancellation experiment. The functional model of SM was first and its use in the data-analysis of single cell recordings was direct and significant.[5] For evidence, we must then turn to other experimental predictions. A complication stands in the way. So far we have described a group of models instead of a theory. To understand how SM is used for predictions, we must characterize the theoretical sense of opponency.

Color scientists agree that the responses of the three retinal cone receptors are somehow "pitted against" each other at the second, post-receptoral stage of visual processing (Hulbert, 1991, 191).[6] This is the theoretical sense of opponency already visible in SM. For example, hue cancellation is subtraction of hue qualia by their opponent hue qualia; opponent hues are assigned opposite "signs" in the two hue channels for their relative strength of response. When

[4] See De Valois, R. I., Abramov, I., and Jacobs, G. H. (1966).

[5] See, e.g., D Hurvich, L.M., and Jameson, D. (1970) and De Valois R. and De Valois, K. K. (1975).

[6] The variation in opponent *models* shows that both how and where this "pitting against" happens is a source of disagreement.

the strength is identified with sensitivity to light, another form for expressing opponency emerges. Cone receptors have three overlapping sensitivity functions. Since opponent channels are post-receptoral they can be expressed theoretically as a function of some combination of cones. The common theoretical idea of opponency is this mathematical one. Opponent processes are linear functions that add and subtract cone output. The mathematical functional idea of opponency brings us to Churchland's opponent processes theory. Churchland (ibid, 167) offers one mathematical version of opponency through linear equations that describe how cone outputs are "pitted against each other." Let us now turn to predictions.

III. Churchland's Novel Color Predictions

Churchland uses so called "habituation" experiments to create "novel" colors. Subjects are first adapted, "habituated," to color stimuli and in a manner that affects only the sensitivity of the second, post-receptoral stage instead of the cone stage.[7] Churchland expresses the idea as "neural fatiguing" (2007). The adapting stimuli fatigue the neurons of the post-receptoral channels. Experimental tasks such as the color identification that Churchland uses are performed after fatiguing. To see how the experiment tests SM, assume adaptation to a stimulus that, according to SM, should affect only one the red-green channel. It is responsible for the whole red-green dimension of color appearance but in varying strength, depending on wavelength. SM specifies the wavelengths where only this channel responds, the locations of the unique hues, red and green. If we habituate with unique red, the prediction is that the same stimulus after adaptation is still only "coded" by the red-green channel. In terms of color appearance, the prediction is a desaturated green. Churchland (ibid, 174) evokes such after-effect colors that follow the opponent "logic" in his readers.

In controlled habituation experiments, the predictions are expressed in a color space. Churchland uses a spindle where hues are expressed in terms of the red-green and blue-yellow axes, as binary combinations of these, where distance from the center indicates degree of

[7] This requires elaborate stimulus setups with slowly changing colors yet ones with a constant average color. And this must be done for extended periods of time for the receptoral "jump" in desensitization to be plausible. It is unlikely that Churchland's demos satisfy the relevant requirements.

saturation, and each equiluminant plane agrees in brightness, the white to black dimension. Predictions about after-effects can be expressed in terms of directions in the equiluminant planes of the color space. SM predicts that stimuli after habituation should retain their direction and change only in distance from the white origin.[8] In this space we can articulate vectors which is how Churchland describes the predictions. For him, predictions are displacements of "coding vectors" in directions that are "directly opposite" in a standard color space; the color of the after-image "must always be located toward a point in the color spindle that is exactly antipodal to the original color stimulus." (ibid, 176)

It is clear in the habituation experiment what kinds of predictions falsify SM. If the after-effects show unexpected changes in hue - changes in direction - in addition to saturation changes, SM is falsified. This is precisely what color scientists have discovered. For example, Webster and Mollon (1991) tested habituation for 16 stimuli across the simple spectrum and found clear hue changes in all of them. Moreover, these included unique hues, stimuli that should affect only one of the channels. Finally, Webster and Mollon found even luminance or brightness changes after adaptation. For them (ibid, 237), the results entail that "there are no chromatic directions encoded by only a single adaptable color channel." And this claim encompasses not only the hue channels but the third luminance or white-black channel of SM. Webster and Mollon suggest a model consisting of "multiple, adaptable channels, each tuned to a different direction in colour space" (ibid., 238). [9]

False predictions from SM have then been discovered and in the very paradigm Churchland mimics in his demonstrations. If we follow Churchland's methodology for ontology, the hypothetical identity between qualia and neural color processes is falsified. This argument, however, may overlook a crucial premise. According to Churchland, the "family of predictions" about opponent after-effects are "well known to visual scientists" even if he does admit that

[8] Since SM harbors the mathematical idea of opponency, the color space's axes can also be expressed in terms of linear functions of cones which is more common to the literature.

[9] These (and other) results (see also Webster and Mollon, 1994) conflicting with SM, have led color scientists to hypothesize multi-stage models with a third stage of processing tuned to various dimensions in color space (see, e.g, DeValois and DeValois, 1993). Perhaps expectedly, some deny the very auxiliary assumption of the habituation paradigm, viz., that adaptation reveals independent processes or channels with specific light sensitivities by fatiguing them. Barlow, for example, thinks that the visual system is more sensitive to the unexpected so that the very concept of "fatiguing" is misleading relative to the natural function of sensitivity and adaptation (see, e.g., Hurlbert, 1991, 192)

these demonstrate the "predictive power" of SM (ibid, 176). Maybe these include Webster and Mollon's studies? Churchland's explicit goal is to argue for a neuroreduction through novel predictions. This leaves open the possibility that the falsifying predictions are according to Churchland not "novel" but "old" or "familiar," in some sense. It is, however, difficult to make sense of this option without a clear definition of novelty and especially when all of the predictions Churchland discusses are based on fatiguing - regardless of their "novelty."[10] But let us quickly review the import of at least some of Churchland's novel predictions for SM.

Churchland's novel colors emerge from circumstances in which the after-effect color is modified by colored surrounds. He creates novel colors by subjecting colored after-effects to simultaneous color contrast and perhaps other anomalous phenomena (e.g., assimilation). As such, there is nothing novel about the phenomena since it is well-known that color appearance depends both on the colors we saw before and that are nearby. Yet obviously no color phenomenology or color appearance space can capture all such possible color phenomena across all possible circumstances! So the novelty of these colors is better based in their experimentally unfamiliar properties that are still predictable from SM. The general idea of the predictions is that color appearance follows the opponent hue "geometry" but now together with changes brought about by unusual brightness/darkness. These are predictable quantitatively in the color space. For example and qualitatively, in a category of predictions Churchland labels "chimerical colors," an "impossibly dark blue" is created when the after-image of a yellow is transposed on a black surround. The prediction is of an "obvious and distinctive hue" that is "more similar to blue than any other hue" but "as dark as the darkest possible black." (ibid, 181-2)

To my knowledge, there are no systematic studies to assess the truth of Churchland's predictions. His demonstrations cannot be used to judge whether chimerical colors fall in the directions and points determined by the coding vectors. Despite the fact that Churchland (ibid, 185) extols SM for "fine-grained predictive prowess" with respect to chimerical colors, the appearances evoked are ambiguous and far too vague to determine the colors not to mention the truth of the predictions. Churchland agrees and admits that "one's individual reactions to the

[10] Churchland never gives a clear definition of "novel predictions" or sticks with uniform use. This is an unfortunate ambiguity since the notion has different meanings in the literature and, arguably, only some of these confer any specific evidentiary import to novel as opposed to old evidence (for a useful overview, see, e.g., Harker, 2008). Habituation results are different from and independent of predictions concerning hue cancellation experiments and the single-cell recordings constitutive of the Standard Model. Moreover, both old and new evidence from the habituation paradigm is evidence relevant for SM.

several tests…should not be regarded as adequate grounds for believing the theory" (ibid, 193). In total, the predictions from the "habituation-like experiments" consist of, one, falsifications of SM and, two, ones whose truth cannot be determined with the exactitude needed. As a consequence, we have a psycho-neural reduction of color qualia that at best remains hypothetical.

Despite its lack of empirical credentials, Churchland does not reject SM as a straightforward falsification would demand. Nor does he explore the heuristic function of the falsification. Instead, for him, the exact results from the habituation experiments are "strictly beside the philosophical issue," reductive explanation, prediction and ontological reduction of qualia (ibid). For him, it is enough that a physical theory can be shown to be able to yield predictions including novel ones about the qualitative nature of subjective experience (bid, 193-4). But does this not degenerate the debate to a conceptual one consisting of conceivability arguments that Churchland and (us) other naturalists despise? After all, predictions as logical consequences of a theory are in some sense conceptual entities unlike their truth-values that concern facts. Yet Churchland thinks that the derivation of novel predictions already shows what a fertile theory and a "sufficiently systematic grasp" of the "structure" of color phenomenology can do, viz., explain and predict (ibid, 194). I disagree and believe that it is only actual positive test results that show whether otherwise merely hypothetical identities do in fact provide a systematic grasp of phenomenology and its mechanisms. More specifically, Churchland's opinion about the insignificance of the truth of novel color predictions is either false or it vitiates the very concept of hypothetical identities. This is a dilemma since both options undermine the proposed neuroreduction of color qualia. Let me explain.

The hypothetical color identity, the neural color code of SM, has not been confirmed through predictions.[11] Its hypothetical nature together with the functional model can only be lessened by true predictions in new experimental paradigms, hence, the fundamental role of novel predictions. Only true predictions can remove or lessen the hypothetical status of the identity statement and, unfortunately, predictions show that the ontological reduction is false or

[11] Instead, the functional color model of SM, hue opponent channels and their sensitivity functions determined by the cancellation experiment, was used to create the hypothesis of a neural code. Of course, the final neural data model of single cell recordings together with the coding assumption "predicts" the cancellation data model but only in a technical sense: the latter is a logical consequence of the former. This is trivial not evidentiary.

that its hypothetical status has not been lessened. Churchland must be false in his contention that the truth of the predictions is irrelevant for the philosophical issues surrounding neuroreduction[12]

Another, more likely reason for Churchland's dismissal of the significance of the truth of the novel color predictions is that the isomorphism-based neural color code is not tested at all by his fatiguing experiments. But if this is so, it is not a hypothetical identity and then Churchland's project is not an "empirical test of the identity theory," despite his claim to the contrary. To see why this might be the case, let us return to the habituation experiment. Regardless of the exact appearance of some green after-effect, for example, the color is admittedly "surprising," for most, yet it is identifiable in terms of the opponent phenomenology, as "desaturated," whitish green. The same is true for all the other novel colors. Since the neural color code is based most significantly on the opponency of neural responses and hue opponency, the application of the same phenomenology across both new and old colors may lead to the belief that the status of the coding assumption is unaffected by the false predictions. But the applicability of the color phenomenology doesn't give evidence for the hypothetical psycho-neural identity, the neuronal color code. Its evidence comes from its association with functional hypotheses and their collective holistic testing across psychophysical experiments. Since there is no "direct" neuroscientific evidence available for the color code that connects hues, conscious qualia, with neural responses, this is the only possibility. Denying the "holistic" inter-level testing scenario for the psychoneural identity statement is tantamount to denying its hypothetical and testable nature.[13] Alternatively, what we have is a group of hypotheses that entail a falsified prediction that still cannot falsify one of the hypotheses in the group, the hypothetical identity. I submit that Churchland's empirical vindication of the identity theory for color qualia is either false in light of best evidence related to his own experimental paradigm or false because the identity between qualia and neuronal responses is not hypothetical but an unfalsifiable axiom.

IV Concluding Remarks

[12] Another possibility is that Churchland has underestimated the theory- or, better, (functional) model-laden character of the original neural model of color-coding opponent neurons. This would be surprising for the founding father of eliminativism that is premised on the theory-ladenness of everything.

[13] I disagree then with some recent interpreters of Churchland such as Schier (2009) who claims that Churchland tests the isomorphism hypothesis itself through his novel colors.

The conclusion for the ontological reduction of color qualia has been negative. But the analysis suggests positive morals for advancing the cause of hypothetical identities including ones based on isomorphisms. Testing verifies and unearths errors. This applies also to hypothetical identities. But a hypothetical identity has the power to unearth errors only if it is falsifiable. Its degree of falsifiability depends on the nature of the identity-statement, the relation. Open-ended identity-statements will be largely unfalsifiable and unprobative. The looser the identity, the less likely it is that empirical facts will conflict with it. Hypothetical isomorphism-based identities can be very exact. Yet these can also suffer from unfalsifiabilty. The case allows us to see why.

Churchland evokes unfamiliar colors that are accommodated by a stable phenomenology. This includes the relation of opponency which, in turn, according to the identity hypothesis, maps on to the neural relation of opponency. So, the same phenomenological language is used which carries the same neural code in its wake. Identifying the *same* structural relation(s) across even admittedly new color qualia is not a novel task with respect to the structural features of color phenomenology. Regardless of how novel the colors are with respect to everyday color experiences, they are not novel predictions for or from the psychoneural identity hypothesis. That is merely applied to new circumstances. To use a slightly modified version of Hesse's (1966) conceptualization of scientific novelty, the "evidence-language" remains the same across the relevant circumstances and experiments, so the epistemology is an application instead of a novel prediction.

How can a hypothetical isomorphism-identity yield novel predictions? It must figure in a theory that allows for the derivation of new psychological relations. Novel predictions for structural inference must feature novel structural relations. How this might work exactly is beyond the scope of this essay. In case this sound too demanding or idealistic, it may be worth pointing out that, according to Köhler (1940), only the mind-brain isomorphism assumption could transform psychology into a progressive, theoretical science and precisely because hypothetical isomorphisms made available further biological knowledge for psychological theorizing. To do so in a methodologically appropriate manner, according to Köhler, requires testing the novel structural features at the psychological level even though these originate at the neuronal brain-level. Köhler's scenario shows how unity or explanation is created: by

hypothetical identities tested through novel psychological predictions including structural features available in phenomenology.[14] Through such a unifying theoretical epistemology, a reductionist scientific ontology is and has been made.

REFERENCES

Churchland, P. (2007). "Chimerical Colors: Some Phenomenological Predictions from Cognitive Neuroscience," in *Neurophilosophy at Work.* Cambridge University Press, pp. 161-197 (Originally published in *Philosophical Psychology,* 2005, Vol. 18, pp. 527-560).

De Valois, R. I., Abramov, I., and Jacobs, G. H. (1966). "Analysis of Response Patterns of LGN cells," *Journal of the Optical Society of America*, Vol 56 (1966), pp. 966-977.

De Valois R. and De Valois, K. K. (1975). "Neural Coding of Color," in E. C. Cartrette and M. P. Friedman (eds.) *Handbook of Sensory Physiology V*, pp. 115-166.

De Valois R. and De Valois K. K. (1993). "A multi-stage color model," *Vision Research*, 33, pp. 1053-1065.

Hardin, C. L. (1993). *Color For Philosophers*. (2nd ed.) Indianapolis, IN: Hacket.

Hardin, C.L. (1997). "Reinverting the Spectrum," in M. Carrier and P. Machamer (eds.) *Mindscapes: philosophy, science, and the mind*. Pittsburgh, PA: University of Pittsburgh Press, pp. 99-112.

Harker, David. (2008). "On the Predilections for Predictions," *British Journal for the Philosophy of Science,* Vol. 59, p429-453.

Hesse, M. (1966). *Models and Analogies in Science*. Notre Dame, IN: University of Notre Dame Press.

Hurlbert, A (1991). "Deciphering the colour code," *Nature* Vol 349, 17, pp 191-193

Hurvich, L.M., and Jameson, D. (1970). "Color vision and color coding," in D.A. Hamburg et al (eds.), *Perception and its Disorders*, Vol XLVIII, Baltimore: Williams & Wilkins, pp. 12-25

Köhler, W. (1940). *Dynamics in Psychology*. New York: Liveright

[14] See also Hardin (1997) for a possible example of this in the case of the opponent process theory.

McCauley, R. N. and Bechtel, W. (2001). "Explanatory Pluralism and Heuristic Identity Theory," *Theory & Psychology*, Vol 11, pp. 736-760

Schier, E. (2009). "Identifying phenomenal consciousness." *Consciousness and Cognition,* Vol. 18, pp. 216-222.

Schouten, M., and de Jong, H. L. (2001). "Pluralism and Heuristic Identification: Some Explorations in Behavioral Genetics," *Theory & Psychology*, Vol. 11, pp. 796-807.

Webster, M.A. and Mollon, J.D. (1991). "Changes in colour appearance following post-receptoral adaptation," *Nature* Vol. 349, 17, pp 235-238.

Webster, M.A. and Mollon, J.D. (1994). "The Influence of Contrast Adaptation on Color Appearance," *Vision Research*, Vol. 34, No 15, pp 1993-2020.

Wimsatt, W.C. (1984). "Reductive Explanation: a functional account," in E. Sober (ed.), *Conceptual issues in evolutionary biology: an anthology* (pp. 477-508) Cambridge, MA: MIT Press