“Categorical perception” and linguistic categorization of color

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Abstract

This paper offers a conceptual clarification of the phenomenon commonly referred to as categorical perception of color, both in adults and in infants. First, I argue against the common notion of categorical perception as involving a distortion of the perceptual color space. The effects observed in the categorical perception research concern color discrimination performance and processing; they need not directly reflect the relations of color similarity and difference. Moreover, the methodology of the research actually presupposes that the relations of similarity and difference do *not* vary with languages. The observed categorical perception effects should be conceived independently of the perceptual color space. Second, I challenge the usual opinion that the existing evidence on infant “categorical perception” allows us to conclude that infants perceptually categorize color, and in particular, that they have perceptual categories that resemble the basic color categories of English. Such conclusions rest on an unjustified interpretation of the infant “categorical perception” findings in terms of adult linguistic categorical boundaries. Based on the suggested new understanding, I propose that the phenomenon, as present in infants, should be conceived and examined as a possible explanatory factor with respect to the existing patterns of color naming in languages of the world.

Keywords: color, categorical perception, categorization, color naming, Whorf, color space

1 Introduction

A substantial part of the recent research in color perception and categorization has been focused on what is known as *categorical perception of color*. With some simplification, categorical perception of color occurs when discriminability of two color stimuli from different categories (such as, “green” and “blue” in English) is increased compared to a pair of stimuli from the same category, despite equal chromatic differences. The present paper examines the notion of categorical color perception, as well as relevant experimental results, in order to assess its possible role in explanation of the observed patterns of color categorization (naming) in languages of the world.

I begin with a consensual picture of the phenomenon in question and of the current state of the field, in section 2. After that, in section 3, I question two aspects of the way categorical perception is usually conceived in the literature. One of them primarily concerns categorical perception as observed in adults (3.1), the other applies to categorical perception as reported for infants and prelinguistic toddlers (3.2). Challenging the standard view of the phenomenon has consequences for the question of the possible explanatory role of pre-linguistic categorical perception in linguistic categorization of color (3.3). The conclusions of the present considerations are summed up in section 4.

2 Categorical perception of color: state of the field

In the recent literature on categorical perception of color, the following definition is generally agreed upon. Perception of color samples is categorical if the discrimination of stimuli across linguistic categories is better (faster, more accurate) than the discrimination of stimuli within a category, in spite of equal perceptual spacing of the stimulus pairs. (Cf. Franklin and Davies, 2006; Clifford et al., 2011; Davidoff and Fagot, 2010; Franklin et al., 2009, 2008a,b; Clifford et al., 2009.) Although Harnad (1987), which is a canonical reference, talks of equal *physical* differences within the stimulus pairs, recent works regularly consider equal *perceptual* spacing as measured in some perceptual color space. Also, several studies note that the contemporary notion of categorical perception is more adequate than the earlier one in that it does not require complete lack of discrimination for pairs within a category. Some authors, echoing Harnad's (1987) definition, describe categorical perception in terms of perceptual *similarity* vs. *difference* in within- and cross-categorical stimulus pairs (Brown et al., 2011): it will be later shown that this way of presenting the phenomenon is inaccurate.

In the past decade, categorical perception (hereafter, CP) of color has been subject to intensive research and effects of this kind have been observed in a variety of experimental settings. That includes different age groups of subjects (adults, infants, and to a lesser extent also toddlers before and after acquisition of color terms), from different language groups (speakers of English, Russian, Greek, Korean, Berinmo or Himba) studied individually and in comparison. Also, it spans various experimental techniques, both behavioral and neurological, suitable to infants (habituation technique, novelty-preference technique), adults (same-different judgement task, odd-one-out judgement task, two-alternative forced choice task), or both infants and adults (visual search task with reaction times measured by means of eye-tracking, measuring event-related potential on the scalp during an "oddball" task). The color samples employed in the experiments are typically differentiated in hue (lightness and saturation remaining constant), with various size of the chromatic difference within the stimulus pairs. The size of the difference within stimulus pairs of the particular research is balanced in a perceptual color space (such as CIELUV) or a color order system (such as the Munsell system).

At present, it is generally acknowledged that there is substantial evidence in favor of both *language-induced* and *pre-linguistic* categorical perception of color. Only few studies (Davidoff et al., 2009; Brown et al., 2011) report failures to find expected CP effects.

On the linguistic side, the evidence is manifold. First, categorical perception occurs for adult speakers only across boundaries of categories that are strongly lexicalized, by means of basic color terms, in the speakers' own language. That is typically shown for particular boundaries by experimental comparison of English speakers with speakers of a language that either subsumes more English categories in one (such as Himba, with a single color term covering green and blue), or "splits" an English category into more (such as Russian and Greek, with their distinct basic terms for light and dark blue). (Franklin and Davies, 2006; Clifford et al., 2011; Davidoff and Fagot, 2010; Franklin et al., 2009; Jraissati, 2012; Ozturk et al., 2013; Winawer et al., 2007.) Second, intensive short-term training in artificial categories (such as, training English speakers to split the scale of green into bluish and yellowish green) induces categorical perception effects at the newly learned categorical boundary. (Özgen and Davies, 2002; Clifford et al., 2011; Drivonikou et al., 2011; Clifford et al., 2012.) Third, in explicit confrontation of adult color perception in the right and in the left visual field, categorical perception effects have been located predominantly in the former. As the right visual field input is processed in the left hemisphere, which is also thought to be responsible for most of language processing, this finding is taken to suggest dependence of adult color CP on color language. (Clifford et al., 2011; Drivonikou et al., 2011; Clifford et al., 2012; Davidoff and Fagot, 2010; Franklin et al., 2008a,b.)

From the Whorfian perspective, it is an important question whether these effects actually reflect influence of language structures on "low level" color perception. Alternatively, they could be explained by the mere fact that cognitive performance in the considered tasks is improved by direct recourse to available linguistic labels. The early findings in categorical perception were susceptible to the latter objection, allowing for explanation in terms of a "naming strategy". For instance, if one is to decide which of two color samples is identical to a sample that was displayed a while before, it is obviously helpful to have the two colors distinguished by color terms, as the verbal label for the first sample is easier to remember than the particular color itself. Also, similarity judgments of color samples can be directly influenced by the naming patterns of the language in question; cf. Kay and Kempton (1984). To the contrary, the above reported evidence for language-induced color CP rests mainly on more recent experimental techniques, in particular on the visual search task and event-related potential (ERP) measuring. These techniques minimize the role of memory and effectively rule out the possibility of improving the task performance via conscious labeling. However, Winawer et al. (2007) report that the cross-categorical advantage in the odd-one-out task can be canceled out by verbal interference. That suggests that even the recently reported adult CP effects may in fact not be strictly perceptual, even though they are not mediated by conscious verbal labeling. We could thus talk more neutrally of "enhanced cross-categorical discrimination", rather than "categorical perception" of color.[1]

Evidence for prelinguistic categorical perception is provided by experiments on infants of 4 to 9 months of age, using various experimental techniques, most recently eye-tracking of the child's visual search as well as ERP measuring. (Bornstein et al., 1976; Franklin and Davies, 2004; Franklin et al., 2005b; Clifford et al., 2009; Franklin et al., 2008a; Ozturk et al., 2013.) The results are supported by a smaller number of studies on toddlers without consistent knowledge of the basic color terms of their language. (Franklin et al., 2005a, 2008b, 2009.) Through assessment of discrimination performance on within- vs. cross-categorical color stimulus pairs, categorical perception has been reported at several categorical boundaries. It is regularly observed at the green-blue boundary, and individual studies have found it at the blue-purple (Franklin and Davies, 2004; Ozturk et al., 2013), red-pink (Franklin and Davies, 2004), green-yellow and red-yellow boundary (Bornstein et al., 1976). Lateralization studies by Franklin et al. (2008a) and Franklin et al. (2008b) report a CP effect only in the left visual field (right hemisphere) for infants and prelinguistic toddlers, as opposed to CP effect only in the right visual field (left hemisphere) for adults and competent toddlers. A common conclusion from all these findings is that human prelinguistic color perception is categorical, and that more research is necessary to clarify the relationship between these prelinguistic categories on one hand and linguistic color categories as well as language-induced categorical perception on the other.

In the following, I will point to some problematic aspects of the usual understanding of both adult and prelinguistic color perception. My aim is twofold. First, the conceptual confusions that exist at both subfields of the categorical perception research arguably lead to inadequate conclusions based on the performed experiments. My clarification attempt will hopefully shed a new light on the CP phenomena as such. Second, prelinguistic (as opposed to adult) categorical perception is of special interest to me for the following reason: only the prelinguistic facts of color perception can be appealed to in explaining the cross-linguistic tendencies that exist in color categorization (naming). (Explanation of such patterns in terms of adult phenomena of color discrimination, which themselves seem to depend partly on categorical systems of particular languages, would be circular.) Correction of the existing conceptual inadequacies should enable us to assess more properly the possible explanatory role of prelinguistic color CP with respect to cross-linguistic color categorization (naming) patterns, as discussed in the rich literature from Berlin and Kay (1969) on. (Cf., among others, Saunders and van Brakel, 1997; Dedrick, 1998; Kay and Maffi, 1999; Roberson et al., 2005; Kay, 2005; Biggam and Kay, 2006; MacLaury et al., 2007;

[1] In the present paper I keep to the standard use of the latter term, following the usual definition.

Kay et al., 2009; Biggam et al., 2011.)

In this paper, I am not concerned with the question, what these cross-linguistic color categorization patterns exactly are and how strong. Over the past several decades, that has been a matter of heated discussions between two opposing camps, the universalists and the relativists, who typically do not agree even upon the empirical methods by which this question should be decided (cf. Lucy, 1997; Saunders, 2000). However, it seems increasingly clear (cf. Kay and Maffi, 1999; Kay and Regier, 2003; Kay, 2005; Kay et al., 2009) that there indeed *are* some non-trivial patterns of how languages of the world divide the color space by their basic color terminologies. (For instance, it is very common for languages to merge what we call in English green and blue into one category; much less so for green and yellow or for blue and red.) A recent modeling approach to color categorization, originating in Steels and Belpaeme (2005), attempts to account for these patterns by means of models which involve, first, some sort of characterization of the color perception by a human individual, and second, simulated evolutionary game-theoretic interaction within a community of such individuals. (Jäger and van Rooij, 2007; Baronchelli et al., 2010; Jameson and Komarova, 2009a,b; Loreto et al., 2012.) In the following, I will argue that the phenomenon of infant "categorical perception", if appropriately conceived, can be represented in models of this recent kind as another factor which might, in interaction with other factors, bring about the existing (and so far unexplained) cross-linguistic color categorization patterns.

3 How to think of categorical perception

3.1 Does categorical perception warp the perceptual color space?

Categorical perception of color is often described (or sometimes even defined) in terms of greater perceptual *similarity* and *difference* between the color samples of, respectively, within- and cross-categorical pairs. (Cf. Harnad, 1987; Brown et al., 2011; Davidoff and Fagot, 2010; Davidoff et al., 2012; Jraissati, 2012; Franklin et al., 2008b). And throughout the field, there seems to be a substantial agreement on the notion that categorical perception effects might be explicable in terms of distortion or "warping" of the perceptual color space, namely by its expansion in some regions and compression in others. Consider the following quotations:

- "It is as though perceptual colour space has been transformed topologically or "warped" [...] The transformation stretches perceptual distances across category boundaries relative to within-category distances." (Franklin and Davies, 2004, p. 351.)
- "Learning colour terms may highlight similarities among colours given the same term and highlight differences among colours given different terms, leading to within-category compression and between-category expansion

of the perceptual colour space, particularly for RVF (LH) [right visual field, left hemisphere] stimuli." (Drivonikou et al., 2011, p. 253.)

- "[T]he results uphold the view that the structure of linguistic categories distorts perception by stretching perceptual distances at category boundaries [...] It would appear that the internal color space [...] is not static; some distances within it are "stretched" or "distorted" by the influence of color labels." (Davidoff and Fagot, 2010, p. 102).

Cf. also Jraissati (2012, p. 441), Clifford et al. (2011, p. 238), and Franklin et al. (2009, p. 243-244). Sometimes, this is more or less explicitly presented as *the* other option besides explanation in terms of "naming strategy" (see the previous section; Franklin et al., 2009, p. 242): either the observed CP effects are a consequence of the subject's recourse to conscious verbal labeling, or they reflect the character of the subject's internal color space and its modifications by language. The "distorted space view" can be seen as a specific construction of the Whorfian thesis that CP effects are indeed perceptual.

I will argue, however, that this way of conceiving the phenomenon, in adults as well as in infants, is wrong. To make my case clear: I do not strongly maintain either a Whorfian or an anti-Whorfian position here. I will only reject the particular interpretation of the existing CP findings which directly links these findings to the character of the subject's perceptual color space. Should there be other feasible constructions of the Whorfian thesis, based on the existing evidence for enhanced cross-categorical discrimination (or categorical perception) of color, my argument will be irrelevant to those.

Perceptual color spaces, such as CIELAB and CIELUV, and color order systems, such as the Munsell system, are intended to represent the ideal space of colors ("*the* perceptual color space"), as given by relations of identity, similarity and difference for a standard observer.[2] Their construction thus involves psychophysical experimentation whereby standard observers' *judgments* of these relations are gathered. Per contra, none of the several experimental paradigms which corroborate adult and infant categorical perception, while not being susceptible to the naming strategy objection, provides us with judgments of color similarity/difference within the employed stimulus pairs. Instead, the experimental techniques measure behavioral or neurological *performance* in discrimination of the paired samples.

The most recent behavioral technique, that is, visual search experiments, does not concern judgments at all, but speed and accuracy in visual detection of a colored target on a background or among distractors that are either

[2]Cf. Fairchild, 2005. To be explicit about the ontological status of color spaces: I take the ideal perceptual color space to be an abstraction over the relations of identity, similarity and difference between particular colors, rather than an independent psychological reality by which such relations could be *explained*. The artificial color spaces are approximations of the ideal color space conceived in this way, imperfectly capturing the similarities perceived by a normal observer. While these spaces are three-dimensional and Euclidean, it is by no means evident that the ideal perceptual color space, or one that were to capture the similarity relations exhaustively, could actually preserve these characteristics; cf. Saunders and van Brakel (1997); Kuehni (2002).

within-, or cross-categorically different. Obviously, one cannot *assess* the color difference between the target and the distractors before one detects the target – but at that point the reaction time is already recorded and that particular trial of the experiment is finished.[3] Also the modern ERP approach in no way deals with color similarity judgments and does not allow conclusions regarding similarity and difference within stimulus pairs. It measures neural responses to presentation of deviant ("oddball") color samples among majority of "standard" samples which are, again, either within-, or cross- categorically different from the deviant.

Admittedly, the older experimental techniques such as the same-different judgment task or the two-alternative forced choice task do involve color identity, similarity and difference judgments. However, they do not elicit judgments of these color relations within the employed stimulus pairs, such as, "sample A is more similar to B than it is to C". Rather, they establish how *fast and accurate* the observers are in reporting that two color samples (a within-, or cross-categorical pair) are different; or which of two samples is identical to a previously displayed one when the other is either within- or cross-categorically different. On the contrary, experiments that do elicit the desirable sort of judgements, such as Kay and Kempton (1984) and Pilling and Davies (2004), are vulnerable to the naming strategy objection, thus not being conclusive with respect to the problem at hand. As rightly noted by one of the reviewers, we are in a certain impasse here: the only CP experiments that really concern perceived similarity, rather than discrimination performance, cannot count, as they do not exclude a naming artifact. (Cf. Roberson et al., 1999, though, for a case of an aphasic patient showing categorical similarity judgments despite difficulties in naming, where the possibility of a naming artifact is disputable.)[4]

The appropriate conclusion from the available evidence seems to be that the discrimination in within-categorical stimulus pairs is significantly slower, more cognitively demanding and more prone to error. Contrariwise, the conclusion that the stimuli in the within-categorical pairs are more perceptually *similar* (less *different*) than those in the cross-categorical pairs either is unjustified, or at least involves a tacit redefinition of similarity (as momentaneous perceptual *discriminability*). The color identity, similarity and difference relations which constitute the ideal perceptual color space and which are metrically represented in artificial color spaces are consensually revealed via gathering observers' *considered judgments* of these relations. They are *not* defined in terms of neurological response patterns, perceptual performance on color sample pairs

[3] Davidoff et al. (2012) distinguish "perceptual similarity" and "categorical similarity" as two modes of judging similarity of colors, the latter being "default" and manifested in "implicit judgment tasks" such as the visual search task. That seems rather confused, since the authors completely ignore the fact that the visual search task involves no similarity *judgment* at all, and they present this task in line with matching-to-sample tasks where similarity judgments are more or less explicitly required (and, not surprisingly, found).

[4] We need not discuss in detail the techniques of the earlier research on infant color categorization (that is, the habituation and the novelty-preference paradigm; Bornstein et al., 1976; Franklin and Davies, 2004), since it is even less clear to what extent the results reflect color similarity relations, as opposed to effects of memory and color preference.

or judgment performance under time pressure. All the results of this latter kind are worth the attention they get in the literature, and they may well support some readings of the Whorfian thesis, but they must not be confused with the relations that are actually captured in perceptual color spaces. For instance, it is conceivable that there is a shade of yellow-green which is (by considered judgment of an average observer) as different from focal green as it is from focal yellow, yet is more easily detectable (in terms of speed or accuracy under time pressure) against focal yellow than against focal green distractors. Of course, drastic discrepancy between similarity of two color points and discrimination performance on them is not to be expected, but that does not imply that the dependence between these two characteristics is trivial. In order to check the strength of the correlation, one needs to conceive them as distinct in the first place. The common talk of the perceptual color space being "warped" in categorical perception (more specifically, compressed in some regions and expanded in others) is not justified by the available CP evidence.

One might reply that the "distorted space view" is not a conclusion drawn from the existing CP findings, but rather a hypothesis proposed to *explain* these findings. Sure, if two color samples are perceptually more similar (in the usual sense of a considered judgment), their discrimination is likely to be slower or more difficult. Thus, if languages to some extent metrically transform the perceptual color space of their speakers, that could provide an explanation for the observed categorical perception effects in adults. These effects, after all, could simply reflect underlying differences in similarity; thus there would be hardly any practical need to contrast discriminability with similarity.

This objection is flawed, however. We cannot explain the reported CP effects in adults by stating that languages transform the perceptual color space of their speakers. The reason is that those very results of CP research *presuppose* that languages do *not* do so. This assumption is taken on with the adoption of a singular color space or color order system as the standard of perceptual equidistance of the stimuli in the employed within- vs. cross-categorical pairs. Color stimuli in the CP experiments have been regularly chosen so as to even up the within- and cross-categorical chromatic difference as measured in CIELUV or the Munsell color system. Once we assume that languages have impact on the perceptual color spaces of their speakers, the existing evidence regarding color CP becomes worthless. That is because we thereby lose the assumption that the within- and cross-categorical stimulus pairs were of equal chromatic difference (represented, say, by 4 Munsell hue steps) for speakers of any particular language (such as English, Greek or Himba). Losing control over the stimuli presented to the subjects, we will have a potential explanation, but we lose the very findings to be explained – there will be no observed categorical perception according to the standard definition.

Language either does, or does not influence the perceptual color space. (Independent reasons for the latter were strong enough to make it a fundamental assumption of virtually all color science of the last hundred years or so: that is why we have only one Munsell color system, one CIELAB, one CIELUV, without language-specific variants.[5]) The existing findings on adult CP cannot validate the former position, since they reflect a different phenomenon; and they cannot be explained from such a position, since they all presuppose the contrary. In this sense, there is no point in either explaining or describing the observed categorical perception in terms of a distorted color space. Insisting on the distinction between the instantaneous discriminability of colors and their perceptual similarity might seem superfluous given how closely related these characteristics seem to be. In my opinion, however, it is the only way to keep the CP research paradigm conceptually coherent.

It should be noted, finally, that there are also some quite recent signs of the confusion between categorical effects and color spaces being overcome in the empirical research: see in particular Bird et al. (2014), who bring evidence to the effect that categorical and metric differences in color are encoded separately in the brain. I believe the philosophical considerations above to be in full accordance with this development.

3.2 How categorical is categorical perception?

In one sense, the question "is color perception categorical?" is simply concerned with whether there indeed are significant CP effects at the assumed categorical boundaries. (Cf. Brown et al., 2011; Jraissati, 2012.) For adults, such effects are taken to strongly support the thesis that linguistic categorical infomation is able to guide discrimination. This section deals with a different sense of the question: does categorical perception, as documented by the existing research, provide us with anything that can be in a strong sense called (perceptual) *categories*? That is, do CP effects divide the perceptual color space into more or less discrete chunks, in a way comparable with how it is typically partitioned by linguistic categories (notwithstanding vagueness)?

In the previous I have argued that all the recently observed CP effects characterize human perceptual performance and processing, and that they must be conceived as distinct from the structure of the perceptual color space. They should not be mistaken for the basic (by all assumptions universal) relations of color similarity and difference. Instead, categorical perception effects should be considered in addition and with reference to the (similarity-based) perceptual color space. For instance, one can compare the perceptual performance in discrimination of equidistant color points in the red vs. the blue region of the space. When a difference is found, it by no means forces the conclusion that the color points in the examined pairs were actually not equidistant. Indeed, once we appreciate the distinctness of the performance and processing issues from the core similarity relations among colors, there seems to be no reason to expect complete homogeneity of the former with respect to the similarity-based color space. (Even if massive discrepancy between instantaneous discriminability, on one hand, and judgment-based similarity/difference, on the other, seems unlikely, as already admitted.)

[5]In the CP context, see the findings to the same effect in Witzel and Gegenfurtner (2013); Roberson et al. (2009)

This conception of color perception, however, makes it apparent that the performance and processing effects can hardly define any "absolute" categories, that is, strictly discrete regions in the color space. They cannot, unless we want to assume that there may be pairs of perceptually different (non-identical) color points which we nonetheless completely fail to discriminate. But that seems to be ruled out conceptually.

Still, it is well possible that these effects define reasonably strong "relative" categories. For instance, it might be that for adult English observers, discrimination performance is differentiated across the color space in such a way that discrimination of equidistant color points is consistently and markedly easier *across* than *within* the regions delimited by the English basic color terms "red", "green", "white", "orange", "brown" etc. Such is, at least, a common picture of the functioning of language-induced categorical perception. In my opinion, much needs to be done in order to confirm this picture. The reason is that the existing studies in support of categorical perception usually compare *one* cross-categorical with *one* within-categorical stimulus pair (or, at best, several within- and cross-categorical pairs), and typically at the green-blue boundary. Clearly, each examined stimulus pair provides just a tiny fragment of all the evidence that would be necessary in order to conclude that English induces strong and consistent "relative" perceptual categories correspondent to its linguistic categories. Most categorical boundaries other than green-blue are virtually unexplored. But overall, the research in language-induced categorical perception appears to be on the right track in gathering the desired evidence, also given that some attention has already been paid to performance differentiation within a category, related to its prototypical structure (Hanley and Roberson, 2011; Jraissati, 2012; Clifford et al., 2012).

In case of infant color perception, the situation is different and requires substantial conceptual clarification. According to the consensual definition, categorical perception of color occurs if there is a cognitive advantage for discrimination of stimuli from different categories, compared to within-categorical stimuli, despite equal chromatic differences. In case of adults, this definition clearly refers to *linguistic categories*; or that is how it is unanimously interpreted and operationalized in research. For infants, no modification of the categorical perception concept has been proposed and the same (underspecified) definition is explicitly or implicitly applied, regardless of the fact that *no linguistic categories can be assumed* in 4-to-9-month-old infants. In the practice of research, it is still the boundaries between adult linguistic categories (in particular, green-blue), what is being examined in the infant CP research. (Cf., among others, Franklin and Davies, 2006; Franklin et al., 2008a; Jraissati, 2012; Ozturk et al., 2013.)

Now, this choice is reasonable only as far as the research question is: does infant color perception manifest CP-like effects at boundaries of adult linguistic categories? To answer this question, it is surely appropriate to compare infants' discrimination performance on a couple of equidistant stimulus pairs within vs. across categories such as blue and green. It is, however, fallacious to infer from positive evidence of this kind that there is *anything* comparable to adult categories in infant color perception. We may insist that we keep labeling those effects “categorical perception”, but “categorical” in this sense will not imply any self-standing *categories*, not even relative ones (in the sense suggested above). My point here goes beyond the trivial one that research on, *e.g.*, the green-blue boundary does not in itself license conclusions with respect to other color categories, such as red or orange. Rather, I claim that an infant CP-like effect observed in stimulus pairs spanning the boundary between the linguistic categories blue and green does not even allow a conclusion to the effect of there being corresponding, blue and green, categories in infant color perception.

Yet there are plenty examples that it is quite usual to conclude from the finding of infant CP-like effects at a particular linguistic boundary to the existence of adult-shaped color categories in infants :

- “[F]our-month-old infants [...] respond categorically to colour. Furthermore, it was shown that four-month-old infants not only have primary categories such as blue and green, but also have secondary categories such as purple and pink.” (Franklin and Davies, 2006, p. 108.)

- “Four-month-old infants categorize a range of colours – blue, yellow, green, red, purple and pink have been tested so far.” (Franklin and Davies, 2006, p. 113.)

- “These studies show that CP effects in infants occur in the LVF [left visual field], while it occurs in the RVF with adults. This suggests that there would indeed be innate categories, independent of language in infants, which would at a later stage be over-ridden by language dependent boundaries [...]” (Jraissati, 2012, p. 444).

- “Our findings provide independent evidence for the existence of color categories in prelinguistic infants [...]” (Ozturk et al., 2013.) “[L]anguage is not necessary for color categories in humans. [...] What are the color categories that infants begin with?” (Ozturk et al., 2013, p. 114.)

- “The relation between prelinguistic and linguistic CP remains unclear. One possibility is that language makes fairly minor language-specific adjustments to a universal set of prelinguistically available categories. Another possibility is that language carves its categories into cognition *de novo*, without building on prelingustically available categories.” (Franklin et al., 2008a, p. 3222.)

- “[W]hat categories are prelinguistically available in the RH? How do these categories compare *extensionally* to linguistic color categories, and is *their extension* governed by similar forces?” (Franklin et al., 2008b, p. 18224, italics are mine and meant to emphasize the strong sense of the infant categories presupposed here.)

The weak point of the standard reasoning, I think, is that CP-like effects at particular adult linguistic boundaries are believed to directly reflect boundaries of infant perceptual categories (presumably in the sense of strong “relative” categories as defined above). That is not justified, since there is no good reason to assume that the regions of the color space[6] where languages place their categorical boundaries are of special salience on the prelinguistic level of color perception.[7] Only if we already presuppose that *either* there are infant perceptual categories corresponding to adult linguistic categories, *or* there are no infant perceptual categories at all, we can regard an observed CP-like effect across the green-blue boundary as evidence for there being categories of green and blue in infant color perception.

Once again: upon the appreciation that instantaneous discrimination performance is a distinct issue from the color similarity relations constituting the perceptual color space, there is little reason to expect perfect homogeneity of the former with respect to the latter. On the contrary, we may expect to find CP-like effects on equidistant stimulus pairs from various regions of the color space, irrespective of where adult categorical boundaries lie. It is surely remarkable that these effects *do* occur in infant color perception at certain adult linguistic boundaries, as demonstrated by a handful of studies from the last decade (Franklin and Davies, 2004; Franklin et al., 2005b, 2008a; Clifford et al., 2009; Ozturk et al., 2013; Franklin et al., 2005a, 2008b, 2009). However, these are, to my knowledge, the *only* locations in the color space that have been examined until now. Since we cannot assume linguistic categories to be of any relevance for infant perception, the well-attested CP-like effect at the green-blue boundary does not in any way guarantee 1) that a similar effect takes place, say, at the green-yellow boundary, and 2) that a similar effect does *not* take place, for instance, in the middle of the green, blue or yellow linguistic category. Moreover, the green-blue boundary is the only linguistic boundary at which infant CP-like effects are supported by a massive body of evidence. For other boundaries, the evidence is thin (blue-purple) or dubious (red-pink, green-yellow, red-yellow; see section 3.3).

We are forced to conclude that contrary to the usual views of infant "categorical perception", on the basis of the existing results, nearly nothing can be said on the question whether infants perceive colors categorically,[8] and if they do, to what extent their categories coincide with the linguistic color categories of any particular language.

[6]Here, I fully adopt the somewhat non-trivial assumption made in all existing research on infant categorical perception, that the perceptual color space and its approximations in the artificial color spaces are reasonably valid even for infants as young as 4 months.

[7]I believe that the possible impression that there are such good reasons is false. In Ocelák I reject the opinion that justification for prelinguistic salience of red, yellow, green and blue (the alleged four "unique hues") can be drawn from neurophysiology of color or from language independent color phenomenology. On the side of psychology, Eleanor Rosch's influential notion of prelinguistically available, universal color categories has been severely undermined by the cross-cultural research of Debi Roberson and colleagues (Roberson et al., 2000, 2005).

[8]The conclusion of Davidoff et al. (2009) is similar, but based on contradicting experimental results, rather than on a general objection as the above.

3.3 Infant "categorical perception" in the modeling of linguistic color categorization?

Clearly, not the adult categorical perception, induced by language patterns, but only the infant CP-like effects can be appealed to in explaining the observed cross-linguistic patterns of color categorization. This explanatory strategy is rather obvious and has been suggested (Clifford et al., 2009). However, it does not seem particularly fruitful as long as we assume that infant "categorical perception" amounts to there being strong perceptual categories for infants, most likely coinciding with a set of basic linguistic color categories of English. For there are many languages that do *not* categorize color like English (as is very patent in Kay et al., 2009).

Nonetheless, the conception of infant "categorical perception" proposed above fits well to a color categorization model of the recent, game-theoretic sort. (Steels and Belpaeme, 2005; Jäger and van Rooij, 2007; Jameson and Komarova, 2009a,b; Baronchelli et al., 2010; Loreto et al., 2012.) Namely, the CP-like effects (read: differentiation of discrimination performance across the color space) can be readily seen as an additional perceptual constraint, besides the very color space characterizing individual color perception, on the game-theoretic interaction of individual agents by which development of linguistic categories can, arguably, be modeled. In this setting, it is not necessary that perceptual categories coincide with the linguistic in order to explain their formation, and there need be no strong perceptual categories at all. Even a feeble performance differentiation over the color space might lead, in interaction with other perceptual and game-theoretic constraints of the model, to the characteristic patterns of color categorization observed in the world's languages. Apart from the very similarity-based metrical relations of colors in standard observers (cf. Regier et al., 2007), or from introducing a realistic proportion of color-deficient agents in the simulated population (cf. Jameson and Komarova, 2009b), performance differentiation is another factor that may promote particular locations for categorical boundaries. A realistic model of an individual human perceiver should include this component; a proper evaluation will then decide whether adding it increases the performance of a color categorization model that is based on game-theoretic interaction of such perceiving agents.

Unfortunately, as already indicated, the available evidence concerning infant discrimination performance is not even remotely complete across the color space. Here, I summarize all the fragmentary findings in this respect. The only region of the color space that is sufficiently covered is the green-blue boundary, at the middle level of lightness. Franklin and Davies (2004); Franklin et al. (2008a,b); Clifford et al. (2009) report CP-like effects on variously spaced equidistant Munsell stimulus pairs in the boundary's neighborhood. Franklin et al. (2005b) and Ozturk et al. (2013) find similar effects on samples that are equidistant according to the CIELUV color space. On the blue-purple boundary, infant CP-like effects have been observed by Franklin and Davies (2004), using Munsell stimulus pairs, and Ozturk et al. (2013), using stimulus pairs equidistant in CIELUV. For other boundaries, the evidence is rather questionable. Franklin and Davies (2004) find a CP-like effect also at the red-pink boundary, but given their novelty-preference method, this finding may also be a consequence of the fact that infants prefer red to pink.[9] Bornstein et al. (1976) report a CP-like effect at the red-yellow, green-yellow and green-blue boundary, but this finding seems not reliable, first, because the employed habituation method does not keep apart perception, preference and memory, and second, because the chromatic differences within the stimulus pairs were balanced in a physical (wavelength), not a perceptual space.

More research on infant performance differentiation across the perceptual color space is thus necessary before this effect can be integrated as an explanatory component into models of linguistic color categorization.

4 Conclusion

In this paper, I have argued that the phenomenon labeled "categorical perception of color", which has been intensively studied in the past decade, is misconceived in the contemporary litrerature in two important respects. This phenomenon, both in adults and in infants, should not be understood as any kind of distortion ("warping") to the perceptual color space: First, because what is observed in the categorical perception research differs from the phenomena which constitute the abstract perceptual color space (even if these two types of phenomena are not unrelated). Second, because this branch of research actually presupposes *invariance* of the color space. As regards the phenomenon observed in infants, I have tried to show that the existing experimental results do not license the conclusion that prelinguistic children categorize color perceptually. Even less does it allow us to conclude that thay have color categories comparable to those of English. The usual assertions to this effect rest on an inappropriate conception of infant color categories in terms of adult, linguistic ones.

Based on both these points, I have suggested that what is called categorical perception of color in infants is more accurately understood as differentiation of color discrimination performance over the perceptual color space. As such, this phenomenon appears to be another factor of human color perception which could be straightforwardly represented in color categorization models of the recent, game-theoretic type. In this way, it could help us account for the existing patterns of color categorization in the languages of the world. Before that, however, the so far fragmentary evidence concerning the phenomenon in infants needs to be considerably extended.

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[9] As attested in Franklin et al. (2008c).

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