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Race and Color: Two Sides of One Story? Development of Biases in Categorical Perception

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Categorical perception is a phenomenon that leads people to group stimuli into categories instead of perceiving their natural continua. This article reviews the literature of two biases connected with categorical perception: categorical color perception and the other-race effect. Although these two phenomena concern distant targets (colors and faces) and imply different biases (one attentional, one mnemonic), they share at least three commonalities. First, they both involve the chunking of continuous dimensions into categories. Second, adult categories are shaped by cultural processes. Third, infants' discrimination performance seems universal and guided by perception. In this article, it is proposed to look for a common developmental mechanism that clarifies the shift from a perceptual to a sociocognitive knowledge of the environment. New perspectives are discussed.

Philosophers have long argued that our perception, rather than reflecting an objective reality, is filtered by our own senses and cognitive schemata. Immanuel Kant, in his "Critique of Pure Reason" (Kant, 1781/1929), offered an extensive dissertation about human knowledge: He thought that people could never reach the perception of what he called "the thing in itself," but only of the "phenomenon," the appearance of real objects as our senses and intellect could capture them.

In effect, years of psychological research seem to prove the accuracy of Kant's intuition: Human beings are immersed in their psychological environment that creates a membrane toward the external world. Physical constraints, cognitive schemata, motivation, stereotypes, and, at the most abstract level, culture are examples of the interface between humans and their percepts (see Fiske, Gilbert, & Lindzey, 2010).

In this broader framework, many researchers have tried to identify the factors that induce perceptual biases: In addition to some general and universal factors related to the physical constraints of our brain and of our senses, there are other cognitive factors linked to the appraisal of sociocultural rules and practices. As part of a larger debate over nature versus nurture and their interaction, researchers have aimed to trace the origins of such perceptual phenomena (see Pinker, 2004).

In this article, we examine two intensively studied and seemingly unrelated biases of perception: the other-race effect (ORE) and categorical color perception (CCP). The ORE, on one hand, is a memory bias involving different ethnic groups, but many studies have shown that it originates from the perceptual encoding phase (Rossion & Michel, 2011). It has been explained both with a universalistic perceptual narrowing (Scott, Pascalis, & Nelson, 2007) and a relativistic categorization–individuation model (Hugenberg, Young, Bernstein, & Sacco, 2010), but its origins and evolution remain unclear. CCP, on the other hand, concerns basic physical properties of the natural environment and is generally explained on the basis of categorization (Berlin & Kay, 1969). A long debate characterized this domain contrasting the supporters of universal and relative causes of this categorization effect (Kay & Regier, 2006).

The first aim of this article is to highlight the commonalities in the literature of these two domains. Moreover, we propose to look at the ORE as a bias that is in part similar to color categorization and in part different because immersed in the social domain. We propose to bring these two research areas together and to exploit the results achieved in one area to promote the comprehension of the other.

The second aim of this article is to examine the developmental trajectories of these biases: Recent studies have highlighted the importance of looking at the evolution and transformation of these

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phenomena. In this way, all different types of factors and variables could be added to the final equation, where they can play complementary instead of opposing roles (see Franklin, Drivonikou, Bevis, et al., 2008; Franklin, Drivonikou, Clifford, et al., 2008). We believe that looking more deeply at the developmental trajectories of these phenomena would help us to understand them better and, possibly, to overcome the nature versus nurture controversy.

The final aim of this article is to propose a common developmental mechanism that, through the acquisition of language and of categorical labels, shifts human comprehension of the world from perceptual discrimination to culturally immersed cognition. In this perspective, we compare color and other-race perception to make a parallel between a domain of the physical and one of the social environment. We posit the presence of a common developmental pathway, with language facilitating and guiding the categorization and discrimination of the stimuli as previously demonstrated (Scott & Monesson, 2009). At the same time, we claim that the social stimuli will be subject to further motivational and intergroup phenomena, which will produce not only intercategorical biases but will also induce differential processes within the same category (categorization–individuation; Hugenberg et al., 2010), depending on the group of stimuli considered (in group vs. out group).

In the following sections, we are first going to review the models that have been proposed in both areas for the adult population and, then, look at the theories concerning the development of these biases in infants and children. In each section, we are going to compare studies that have provided support for the perceptual or cultural explanations. Subsequently, we will integrate the two bodies of literature, by proposing to look at these phenomena as connected in their behavioral results and in the mechanisms of their development. Moreover, new theoretical implications and future directions are discussed.

A Parallel Story: Explanations of the ORE and Categorical Perception of Color in Adults

The ORE, also called cross-race effect or own-race bias, consists of a better recognition performance for faces of one's own-racial group compared to faces of other racial groups. Research on this phenomenon has been carried out for more than 40 years (Malpass & Kravitz, 1969), and its reliability and stability have been confirmed by numerous studies (for a review, see Meissner & Brigham, 2001). The phenomenon cannot be attributed to greater physiognomic similarity among specific ethnic groups, given that the ORE has been found among Caucasian, African, Hispanic, and Asian participants (Gross, 2009; Meissner & Brigham, 2001; Sporer, 2001). Early on, researchers shifted their attention to the psychological mechanisms guiding the bias; this led to flourishing of theories stressing the importance of different perceptual and cognitive factors (for a review, see Hugenberg et al., 2010).

A first set of explanations focused on the perceptual expertise and interracial contact as possible causes of the bias (e.g., Chiroro & Valentine, 1995). Under this broad umbrella, we can place different theories concerning both the style of perceptual elaboration and the strategies of face representation in memory (for review, see Young, Hugenberg, Bernstein, & Sacco, 2012). The general idea behind these theories is that people are usually more exposed to faces of their own ethnic group (contact) and hence become experts in processing and remembering their characteristics (Rossion & Michel, 2011). From this perspective, the origin of this bias is explained by different perceptual expertise.

Along with the contact hypothesis, a second set of explanations has made use of sociocognitive factors to account for the ORE (for a review, see Young et al., 2012). All of these theories rely on the phenomenon of social categorization as the basic cause of the other-race recognition deficit (see also Hugenberg et al., 2010). The unifying idea is that categorizing a face as belonging to an out group inhibits further elaboration of its characteristics as an individual. This will then result in a shallower encoding and reduced mnemonic performance for that face.

In a clearly distinct and separate area of psychological research, literature of CCP has produced similar findings and has run into similar contradictions between perceptual and cultural factors. Categorical perception refers to a well-known perceptual phenomenon that leads people to divide stimuli into categories, instead of grasping their natural physical continuum. This effect has been highlighted in many research areas including the perception of sounds (Schouten & van Hessen, 1992), faces (Levin, 2000), and concepts (Newell & Bülthoff, 2002). As a consequence, this arbitrary division also affects judgment; people tend to see objects as more homogeneous when belonging to the same category and as more different when belonging to different categories, even when the objective perceptual distance between each stimulus pair is kept constant (see Tajfel, 1982). One particularly flourishing area of research in this respect is the one on color perception. For many years (Berlin & Kay, 1969; Bornstein & Korda, 1984), researchers have demonstrated that people are faster in distinguishing two colors belonging to different categories (e.g., blue and green) than two colors belonging to the same category (e.g., two different blues), even when the distance in hue is objectively the same. This effect has been shown with different behavioral and attentive tasks such as the same versus different judgment task (e.g., Bornstein & Korda, 1984), the two alternative forced choice task (e.g., Roberson & Davidoff, 2000), and the visual search or target detection task (e.g., Gilbert, Regier, Kay, & Ivry, 2006).

This convergent evidence demonstrating the existence of the phenomenon is, however, accompanied by a strong divergence in the explanation of its causes (see Kay & Regier, 2006). The central debate took place within the general framework of the nature–nurture debate. From the former point of view, the categorical division is due to the shared perceptual nature of our visual system and brain functioning. According to this perspective, categorization reflects a natural tendency to divide colors along preconceived boundaries (Berlin & Kay, 1969). In this sense, the universal position has many commonalities with the expertise hypothesis proposed for the ORE. In the case of color, it is presumably the existence of innate perceptual capabilities that leads people to see the environment in a preconceived way (Berlin & Kay, 1969). In an analogous way, proponents of the expertise hypothesis suppose that the ORE is primarily a perceptual bias. Although not reflecting an innate predisposition (Kelly et al., 2005), it is strictly linked to the differential stimulation of the visual system by whatever stimuli are most frequent (i.e., faces of the surrounding environment; Chiroro & Valentine, 1995). In both cases, the human perceptual system takes center stage in the respective explanation.

According to the cultural point of view, instead, color categories reflect sociocultural and linguistic practices and are superimposed on our perception (Roberson, Davidoff, Davies, & Shapiro, 2005). This view relies on the Whorfian hypothesis (Whorf, 1956/1998) concerning linguistic relativity: It affirms, in effect, that cultural labels create categories, which, in turn, guide individual perception. This perspective may be seen as similar to the sociocognitive explanation of the ORE. The ORE has been shown to be malleable and, in fact, disappears when other social categories become salient (e.g., the university; Hehman, Mania, & Gaertner, 2010). This effect is often achieved using verbal and socially relevant labels, and in this sense, the perceptual discrimination is fostered or inhibited through these cultural signals.

In the following sections, we are going to look more in detail at these two alternative theoretical positions and at the empirical evidence sustaining each interpretation.

Experimental Support for the Role of Perceptual Experience in Adults

In the ORE literature, the contact hypothesis has been assessed by correlating the perceptual exposure of the participants to other-race faces with the recognition bias (Chiroro & Valentine, 1995; Sangrigoli, Pallier, Argenti, Ventureyra, & De Schonen, 2005). One study has specifically investigated the ORE in people adopted by other-race parents (Sangrigoli et al., 2005) and found that Korean adults adopted by Caucasian families exhibited an inverted ORE in favor of Caucasian faces. Along similar lines, the adult literature suggests that the superior recognition for own-race faces, although present in all groups, may be more evident among Caucasian participants (see Meissner & Brigham, 2001), presumably because people of other ethnic groups generally have much more experience with the Caucasian majority group than vice versa. This hypothesis has been confirmed by studies showing an inverse correlation between the ORE and the contact rate with other-race people (e.g., Chiroro & Valentine, 1995). These findings lent strong support to the claim that recognition ability is, at least in part, driven by perceptual experience.

Nevertheless, many authors have questioned the effects of perceptual expertise (Hugenberg et al., 2010; Ng & Lindsay, 1994; Young et al., 2012). Some studies have failed to find a correlation between contact and the ORE (e.g., Ng & Lindsay, 1994), and, in their meta-analysis, Meissner and Brigham (2001) found that only 2% of the variance in the bias could be attributed to the experience with other-race faces. Thus, although experience with other-race faces may affect the recognition ability of adults to some degree, the magnitude of its contribution seems to be rather modest.

Finally, there are some variations in the bias that cannot easily be accounted for by differential perceptual experience alone. For example, MacLin and

Malpass (2001) added racial markers (e.g., Hispanic vs. African hairstyle) to race-ambiguous faces (Hispanic or Black). Although faces were identical except for the racial marker surrounding the face (hair), Hispanic participants recognized the ambiguous faces better in the presence of a typically Hispanic than in the presence of an African hairstyle, suggesting that motivational factors may come into play. To summarize, although this line of research has shown some link between experience and ORE, the perceptual expertise cannot be the only predictor for the same-race recognition advantage.

In the field of CCP, the universalistic account has also offered a perceptual and innatistic explanation. According to this position, common perceptual functioning accounts for people's shared categorical perception (Berlin & Kay, 1969; Regier, Kay, & Cook, 2005). At least for basic color categories, there seems to be great commonality between cultures in color labels, and many studies have identified basic universal invariants of color clustering (for a more complete review, see Regier & Kay, 2009). In a pioneering study, Berlin and Kay (1969) analyzed color labels in 20 different languages and came to the conclusion that color names can vary between societies but in an organized and somewhat predictable way. They individuated 11 common and basic color terms present in almost all languages. Moreover, the authors found an organized pattern for the increasing number of color names in a language: For example, if a language possesses only two color names they will be associated with the white versus black distinction. As the number of color names increases first red, then green and yellow will be added, and so on (Berlin & Kay, 1969). This study has been criticized for its almost exclusive focus on industrialized countries (17 of 20) and for the fact that all the participants were at least bilingual, speaking also English (see Regier & Kay, 2009). In this perspective, the survey cannot be considered truly representative of world languages, but it has surely opened the way to a perceptual explanation, suggesting that there may be some universal constraints shaping color category formation.

Following the publication of these results, a World Color Survey was undertaken in 1976 (Kay, Berlin, Maffi, Merrfield, & Cook, 2009) with the objective of collecting as many intercultural data concerning color labels as possible and providing more systematic evidence for Berlin and Kay's (1969) universal constraint theory. This study lasted 4 years and included participants from 110 unwritten languages tested with 320 Munsell color types. This data set was analyzed by many researchers (for more information, see Regier et al., 2005), who found converging evidence for some common, though not completely coinciding, color names. Regier et al. (2005) suggested a model where cross-cultural color category formation is driven by the best example prototypes of colors (focal foci); for at least 6 of the 11 English basic colors (white, black, red, green, yellow, and blue), there is an agreement on the focal foci in unwritten languages. Also in this field, the universalistic position did receive partial support, but it cannot provide a comprehensive explanation, given that studies showed only partially overlapping categories and that some studies have found profound differences in CCP across various cultures (e.g., Roberson & Davidoff, 2000).

Experimental Support for Sociocultural Factors

In the literature concerning race discrimination, Levin (2000; Levin & Angelone, 2002) has shown that race, much like color, is perceived in a categorical (rather than continuous) way and that race provides a basis for grouping faces. He found that categorical perception is stronger for morphed face continua that cross the racial boundaries compared to morphed face continua within the same racial group (Levin & Angelone, 2002). Levin (2000) proposed a model according to which race detection and categorization are the primary processes of face elaboration: Race is considered a powerful visual cue, and the analysis of this characteristic drains attentive and mnemonic resources from the elaboration of other facial features. Moreover, this categorization seems also driven by sociocultural factors rather than pure perception. For instance, research on the hypodescent effect (defined as the automatic assignment of people of mixed union to the less socially privileged group) showed that people categorize mixed-race faces as belonging to the ethnic minority group. Presumably, this effect is due to the fact that majority faces are learned earlier and deviations from the majority stand out as the only characteristics that differ from the reference group (e.g., Halberstadt, Sherman, & Sherman, 2011). In this respect, the intercategorical cutoff is also mostly guided by sociocultural rather than perceptual factors.

Other social cognitive theories have focused more explicitly on motivational factors. These models generally rely on the idea that people have a limited amount of cognitive resources and should allocate them to the most relevant targets. As a result, in-group faces should foster a deeper type of elaboration (Sporer, 2001), whereas out-group faces are subject to cognitive disregard because they are perceived as socially less relevant (Rodin, 1987). This second group of theories has shown how much race is an important feature for categorizing a face and how this categorization leads, subsequently, to a different perceptual and cognitive treatment of these stimuli, depending on in-group and out-group processes.

Recently, Hugenberg et al. (2010) have proposed a new model, the categorization–individuation model, trying to connect the three main factors identified in the ORE phenomenon, namely perception, categorization, and motivation. The authors recognize the important role of perceptual expertise in the other-race recognition deficit; however, from their perspective, intercultural contact will be beneficial only to the degree to which it allows people to learn to individuate out-group members. Hence, not all kinds of exposure result in better face recognition abilities; instead, an active and motivated experience with a group of faces is needed to acquire (or maintain) the capacity to remember them.

The central factor remains, nevertheless, the categorization process that, according to the authors, is the initial stage of the categorization–individuation model and is considered automatic and unavoidable (Hugenberg et al., 2010). From this perspective, however, it is not only the race that elicits categorization, but any type of socially or culturally relevant identity can play an important role in creating in-group and out-group clusters, with the resulting homogenization of the latter. This claim is consistent with the findings on other-age (for review, see Rhodes & Anastasi, 2012) and on other-gender biases (Scherf & Scott, 2012), and supports the idea that the ORE is part of a more general phenomenon of in-group out-group differentiation (see also Sporer, 2001). Indeed, in the third step of the model, the categorization process culminates in fostering or reducing the motivation to process a particular face at a deeper level of perceptual encoding. In the case of race, people are usually more willing to individuate faces of their own race, whereas they are less motivated to enhance the encoding process for faces of other races (Hugenberg et al., 2010). Nevertheless, when a particular situation stresses another social identity or group belonging, the bias may shift. Consistent with this idea, a study by Hehman et al. (2010) has shown that, depending on the type of group categorization, people showed different types of memory biases. When faces were spatially grouped by race categories, participants showed the typical ORE, but when faces were spatially grouped according to university affiliation, participants remembered the faces of their own university better than those of an out-group university, regardless of race (Hehman et al., 2010). Similarly, Van Bavel and Cunningham (2012) replicated this effect with the minimal group paradigm, finding better recognition for arbitrarily defined in-group faces, independent of race. Many other studies have shown that the encoding of and memory for a particular target face depend greatly on the categorization and labeling of this face to the in group or out group (Chen & Hamilton, 2012; Pauker & Ambady, 2009). Taken together, these results provide converging evidence in favor of the categorization–individuation model. Although this model has successfully integrated apparently incompatible results for the ORE in the adult literature, it is somewhat difficult to reconcile with the infant literature. Along with other social cognitive theories, this model has, in fact, been criticized for not accounting for the early emergence of the ORE (Scherf & Scott, 2012).

In the area of CCP, the relativistic position has built its theoretical background on the Whorfian hypothesis, an intriguing perspective, according to which thought and understanding of reality are shaped by our linguistic practices (Whorf, 1956/1998). Many studies have tried to find evidence for this hypothesis also in the field of color perception (e.g., Roberson & Davidoff, 2000; Roberson et al., 2005). Researchers have observed that different populations and cultures possess diverse names for color categories; for example, English speakers have "blue" and "green" labels, without distinguishing between different tones of blue. In contrast, the Greek language distinguishes light blue ("ghalazio") from darker hues ("ble," Athanasopoulos, 2009); conversely, Himba's tribal people do not possess "blue" and "green" color names at all but use a single label for both (Roberson et al., 2005). Testing different populations allowed researchers to test the relativistic Whorfian hypothesis: They discovered that CCP (the phenomenon of a faster discrimination for between category stimuli) occurs only when people possess linguistic labels for a given color category. For example, Himba people are no faster in distinguishing a blue–green pair compared to a blue–blue or green–green pair, presumably because they are lacking the respective color names in their language (Roberson et al., 2005). Over the years, many similar cross-cultural studies have supported the idea of a cultural influence on CCP (Athanasopoulos, 2009).

Another important claim in support of the relativistic hypothesis is the finding that categorical perception of color is more robust in the right visual hemifield (Gilbert et al., 2006). This result suggests a stronger categorical processing of color in the left hemisphere, which is the location of many language-related brain areas and has been shown to be involved in many linguistic tasks (Gilbert et al., 2006). This finding was further supported by neuropsychological studies. In particular, ERP components such as the visual mismatch negativity (Mo, Xu, Kay, & Tan, 2011) and the N2pc (Liu et al., 2009), two attentive electrophysiological components, are wider for between-category pairs compared to within-category pairs. This difference, however, is present only when the stimuli are presented in the right visual hemifield. Moreover, other neuropsychological studies showed a language-area activation during color discrimination tasks (e.g., Siok et al., 2009), providing convergent evidence in favor of a linguistic influence in categorical perception.

Despite the robust empirical evidence, the strong relativistic position has also been criticized (Holmes & Wolff, 2012) and does not seem satisfying from a developmental point of view, because it cannot easily account for color perception of prelinguistic infants (Franklin & Davies, 2004). In particular, some studies have failed to find cross-cultural differences in toddlers (Franklin, Pilling, & Davies, 2005) or evidence for the general right visual hemifield predominance in CCP (Witzel & Gegenfurtner, 2011). Moreover, even if one accepts the existence of the right visual hemifield predominance in categorical perception, doubts remain about the linguistic account of the phenomenon (Holmes & Wolff, 2012). Holmes and Wolff (2012) found the categorical perception for novel object categories to be lateralized on the left hemisphere for both labeled and for unlabeled categories. The authors concluded that there might be a more general left-lateralized effect that is unrelated to language.

To summarize, the phenomenon of CCP, similar to the ORE, exhibits opposite findings in the adult population, which seem to sustain rival explanations. On one side, visual constraints (Kay et al., 2009) and perceptual exposure and expertise (Sangrigoli et al., 2005) appear to play an important, but not exhaustive, role in the explanation of these biases. On the other side, sociocultural (Hugenberg et al., 2010) and linguistic influences (Roberson & Davidoff, 2000) seem to offer a valid, alternative model that can account for the great malleability and plasticity of these phenomena in the adult population (see Appendices S1 and S2, for more details on adult studies). To trace a more accurate and complete picture of these phenomena, we now turn the attention to the developmental studies that have been conducted in both these research areas. On this ground, researchers have often tried to fight a decisive battle, looking for the potential originating factors that generate these biases. To the contrary, we believe that a developmental approach offers a unique possibility to identify an inclusive, rather than exclusive, progression of these phenomena, which reflects the complementary role of both nature and nurture.

The Developmental Pathways of the ORE and of the CCP

In order to provide an answer to the opposing factions, research that originated in the adult literature has expanded to infant and child populations in order to test how and when these biases originate. Scholars have examined prelinguistic infants and children to look for differential influences of the natural and cultural environment.

In the face perception literature, the ORE appears surprisingly early in life: At 3 months of age, infants already show both a better recognition of (Sangrigoli & De Schonen, 2004a) and a preference for (Kelly et al., 2005) own-race faces. In the experiment of Kelly et al. (2005), infants spent a significantly greater amount of time looking at own-race faces than at other-race faces. For the infant literature, therefore, we will refer to the ORE as both the greater recognition ability and preference for own-race faces. Even though some studies have found it at 3 months of age, this bias is believed to become stable between 6 and 9 months of age (Kelly et al., 2007).

Moreover, the processing style of own- and other-race faces seems to follow a narrowing pattern until it reaches an adult-like performance. At the beginning, infants use a holistic encoding strategy for both own- and other-race faces, but starting at about 8 months of age, they maintain a holistic elaboration only for faces of their own race (e.g., Ferguson, Kulkofsky, Cashon, & Casasola, 2009).

The findings of an ORE at such an early stage of development led scientists to argue for a perceptual explanation of the bias (Kelly et al., 2007; Scott et al., 2007). The perceptual narrowing model continues to be one of the best domain general explanations to account for the development of the ORE and of other perceptual biases during infancy (Scott et al., 2007). The common idea behind this perspective is that, because of repeated experience with certain stimuli, humans become experts in some domains (here, in-group faces) but gradually lose the ability to distinguish other types of targets (out-group faces).

Even though the perceptual explanation of the ORE is most prominent in the developmental literature, some researchers have started to highlight phenomena connected to categorization and motivation as possible predicting factors of the ORE in young infants and children (see Scherf & Scott, 2012). These accounts stress the role of labeling as a moderator for categorical versus individual learning (Hadley, Rost, Fava, & Scott, 2014).

Also in the area of CCP, infant studies have provided support for the presence of universal color categories (Franklin & Davies, 2004). Nevertheless, a new stream of research has shown some significant differences between infant and adult performance in color discrimination (Franklin, Drivonikou, Bevis, et al., 2008), raising doubts about the unique influence of perceptual factors. Moreover, studies with toddlers have highlighted the role of cultural factors in perception, especially with regard to the acquisition of color names (Franklin, Drivonikou, Clifford, et al., 2008), laying the foundation for a new theoretical framework of development.

Experimental Support for the Role of Perceptual Experience in Infancy and Childhood

As mentioned earlier, the ORE in infancy is predominantly explained by the perceptual narrowing theory (Scott et al., 2007). Beyond face discrimination, infants also show own-group biases for linguistic discrimination, intersensual modality perception (face and voice matching), and even metrical structure in music (see Scott et al., 2007). These results seem difficult to reconcile with adult theories of the ORE involving more cognitive and motivational factors (see Hugenberg et al., 2010; Sporer, 2001). It is unlikely that infants at just 3 months of age could make distinctions based on factors other than perception and experience. Even if motivation may still play a significant role in directing the attention of young infants (Scherf & Scott, 2012), it is more likely to reflect the instinctual sense of survival than the adult-like in-group favoritism. Moreover, a study has directly investigated the link between the ORE and the categorization of facial stimuli in infants of 6 and 9 months of age (Anzures, Quinn, Pascalis, Slater, & Lee, 2010). The authors found that the ORE was present in both age groups, but the ability to categorize faces based on race was exhibited only by the 9-month-old group (Anzures et al., 2010). This seems to support the idea that perception precedes categorization in the establishment of the ORE.

Some studies also tested the perceptual narrowing hypothesis in infants, trying to find a direct link between experience and other-race perception. Bar-Haim, Ziv, Lamy, and Hodes (2006) compared three groups of 3-month-old infants, namely Caucasian infants living in a Caucasian context, African infants living in an African context, and African infants living in a Caucasian context. Results showed that only infants living in a context matching their ethnic group showed a preference for own-race faces. The authors interpret these results as the effect of the exposure to faces on the ORE. Moreover, a recent study showed that early deprivation of other-race experience in infancy leads to a lower ability to recognize emotions of other-race faces and to a greater amygdala activity in response to those faces in later childhood (Telzer et al., 2013). The authors concluded that “the heightened amygdala response observed [. . .] may suggest that out group faces are both relatively novel and particularly salient” (Telzer et al., 2013, p. 13487). These results seem to suggest a direct effect of early experience on preference and on discrimination abilities for other-race faces. Finally, perceptual training studies have also provided support for the perceptual narrowing hypothesis (Anzures et al., 2012), showing that even rather short sessions of exposure to other-race faces are able to eliminate the discrimination bias; surprisingly, this holds even for 9-month-old infants that had previously displayed the ORE (Anzures et al., 2012). Together, these studies suggest that early experience with a group of faces may have important and long-lasting effects on their elaboration and recognition.

The ORE has also been tested in populations of children from 3 to 10 years of age. The developmental path of this bias is not yet fully established with some studies finding a stable ORE for all age groups, starting from 3 years of age (Pezdek, Blandon-Gitlin, & Moore, 2003; Sangrigoli & De Schonen, 2004b; Suhrke et al., 2014), and other studies evidencing a developmental increase in the bias from 5 to 8 years of age (Balas, Peissig, & Moulson, 2015; Chance, Turner, & Goldstein, 1982; Goodman et al., 2007). These different findings are not yet fully explained by any integrated model. Some researchers have hypothesized that, because of the general improvement in recognition performance during childhood, the task used in the experiments was too difficult for the younger age groups and led to a floor effect (Chance et al., 1982; Sangrigoli & De Schonen, 2004b). Other researchers, instead, have hypothesized that the ORE remains fluid during the first years of childhood and that these findings do reflect a not fully established bias (Goodman et al., 2007). From the perspective of the perceptual narrowing, it is not clear whether increasing experience with other-race faces during childhood has an influence on the ORE or whether early experience during infancy is sufficient to impress a stable bias.

One study has specifically investigated the contact hypothesis during childhood. Asian children, adopted by Caucasian families when they were infants or toddlers (between 2 and 26 months of age), showed a comparable recognition for both Asian and Caucasian faces (De Heering, De Liedekerke, Deboni, & Rossion, 2010). These results support explanations of the ORE based on perceptual expertise and interracial contact.

Despite the considerable support for perceptual expertise as a cause of ORE, findings are not fully compatible and leave many questions open. In particular, it is unclear which kind of experience is needed to reach expertise in recognition. Is mere exposure sufficient or do additional factors need to be present? If so, which ones? Are only perceptual variables involved or may cognitive and motivational processes play an additional role, as suggested by Hugenberg et al. (2010)? Moreover, it is unclear how long the perceptual exposure has to last in order to have an impact; the idea that the ORE may be caused by predominant and prolonged exposure with own-race faces clashes with studies demonstrating that a short perceptual training, even in the case of adults, improves recognition performance for other-race faces (Young et al., 2012). In summary, perceptual exposure and expertise can play an important role in helping discrimination abilities for a group of stimuli; however, the definition of perceptual expertise seems to be too vague, and it does not describe the processes taking place during the experience that should, in turn, account for the recognition improvement.

In the area of CCP, studies with prelinguistic infants have also confirmed the universalistic hypothesis. These studies showed that 4- and 5-month-old infants already display a categorical perception of colors; moreover, they seem to possess the same categorical cutoffs as adults do (Franklin & Davies, 2004; Franklin, Pilling, et al., 2005). Later in the development, toddlers' performance on categorical perception of color shows no further improvement as they acquire color terms (Franklin, Clifford, Williamson, & Davies, 2005). Franklin, Clifford, et al. (2005) tested English and Himba language learners on a series of color categorization tasks. Results showed that toddlers categorize stimuli with the same accuracy, irrespective of their language capabilities. Finally, in naming and comprehension tasks (Pitchford & Mullen, 2002), children have been shown to create almost the same color categories as adults, even though not in the same order predicted by Berlin and Kay (1969). Taken together, these results can hardly be reconciled with a sociocultural perspective and seem, instead, to be accounted for by perceptual factors.

However, also in this area arguments have been made against a unique and exclusive perceptual explanation. Despite the presence of CCP in young infants (Franklin & Davies, 2004), results with color-learning toddlers are not univocal, with some findings showing the influence of linguistic knowledge (Goldstein, Davidoff, & Roberson, 2009). Moreover, even if the behavioral categorization remains the same, other lines of research have started to highlight that the cognitive pathway could be influenced by color term acquisition (Franklin, Drivonikou, Clifford, et al., 2008).

Experimental Support for the Role of Categorization and Motivation in Infancy and Childhood

Although not directly addressing the ORE or CCP, other developmental studies have investigated the type of experience needed to foster expertise for a wide range of stimuli, including objects (Scott, 2011) or other-species faces (Scott & Monesson, 2009). These studies took, again, perceptual narrowing as the starting point, differentiating between the individual and the categorical level of training. For instance, Scott and Monesson (2009) found that the other-species bias could be eliminated in infants of 9 months of age, only when the babies were trained to associate individual names to different monkey faces but not when they were trained to associate these same faces with the categorical label of "monkeys." These results are quite consistent with Tanaka and Pierce (2009) observations on the ORE in adults. These authors trained Caucasian participants to distinguish African and Hispanic faces. The faces of one group, Hispanic or African depending on the condition, were presented linked with their category label (e.g., "African American"), whereas the faces of the other group were linked to different individual names (e.g., "Joe," "Bob"). Only the training connecting faces with individual labels improved the recognition performance of the participants.

Together Scott and Monesson's (2009) and Tanaka and Pierce's (2009) studies suggest that the ability to discriminate faces of out-group members (including other species) only improves through experiences that foster the individual level of knowledge, whereas the mere exposure to such stimuli at the category level is insufficient. Labeling and categorization seem to work jointly by directing attentive and cognitive resources toward different features. These results suggest that social and cultural factors may exert a remarkable influence on people's recognition ability. For instance, the verbal behavior of caregivers, referring to out-group members either with individuating labels such as names or with categorical labels may, to a large degree, determine whether babies will learn to differentiate people belonging to other groups. At the most general level, these results show that individuals learn to differentiate whatever a culture and its language happens to stress.

From a more functionalist perspective, Scherf and Scott (2012) have recently argued that the presence and evolution of these face discrimination biases are due to the demands of different developmental tasks that babies need to accomplish. In the first year of life, infants will logically pay attention primarily to their caregivers because they are the source of their sustenance and well-being. In this case, caregivers' characteristics such as race, gender, and age will be those best elaborated and remembered. In subsequent years, when the primary objective is to establish relationships with peers, the authors predict a reorientation of attention to same-age faces, with a strengthening of the same-age bias. This theory then suggests that motivational factors are the best predictor of the ORE.

Research with children has also highlighted sociocognitive influences on the ORE. Studies assessing the correlation between the ORE and the contact rate with other races have shown that mere exposure is not sufficient to reduce the bias in recognition (Feinman & Entwisle, 1976; Goodman et al., 2007; Walker & Hewstone, 2006). Besides, the experience in individuating other-race faces seems to be a good predictor of the ORE (Goodman et al., 2007; Walker & Hewstone, 2006). Moreover, the ambiguous-race illusion, a recognition bias caused by adding racial markers to a mixed-race face (MacLin & Malpass, 2001), was found in children starting from 2.5 years of age (Shutts & Kinzler, 2007). In this study, Caucasian children were presented with Caucasian African morphed faces that were paired with an unambiguously black or white face, presented as "sibling" of the target face. Children recognized the morphed faces better when they were paired with a Caucasian (rather than Black) "sibling," but only if the "sibling" faces were those used to create the morphed face, that is, if they were objectively similar to the target face. The authors interpreted these results as the effect of the nonambiguous face to help the racial reconstruction of the morphed one and, in the end, to assign it to a known category.

Taken together, these different models and theories go beyond a purely perceptual explanation of ORE, starting to depict a multifaceted scenario, where various factors play different and complementary roles in building a complex phenomenon. In this framework, clear analogies emerge to the sociocognitive literature on adults (Hugenberg et al., 2010), although the transition from a perceptual discrimination to a more cognitive and categorical one is not yet well established.

In the area of color perception, there appears to be a concurrent and possibly complementary role of both perceptual, universal predispositions and sociocultural, cognitive influences on the composition of categories. Some authors have already tried to depict a multifaceted picture, showing the need of both types of accounts to jointly explain the complex results of CCP (Regier & Kay, 2009). Moreover, some new studies seem to reconcile the many faces of CCP using a developmental explanation. A first study by Franklin, Drivonikou, Bevis, et al. (2008) compared the performance of CCP of adults and 4- to 6-month-old infants. Specifically they tested the right visual hemifield superiority hypothesis that may account for the linguistic influence of the phenomenon. They confirmed the effect for the adult sample but found a surprisingly inverted effect for infants; that is, infants showed a stronger CCP in the left visual hemifield (Franklin, Drivonikou, Bevis, et al., 2008). In a second study, the authors then tried to individuate the stage of this inversion and tested toddlers between 2 and 5 years of age (Franklin, Drivonikou, Clifford, et al., 2008). During this age span, children increase their vocabulary considerably, including color names: From a more perceptual knowledge of the stimuli, they progressively get attuned to their linguistic and cultural environment. The authors, indeed, found an opposite hemispheric predominance in toddlers who have already learned color names compared to toddlers who were still learning them. Toddlers who knew color names showed a right visual hemifield effect as adults do, whereas toddlers who did not yet know color names showed a left visual hemifield predominance, as infants do (Franklin, Drivonikou, Clifford, et al., 2008).

These results open a new perspective on CCP, suggesting that infants initially rely on a more perceptual process to make their judgments, which is carried out by the right hemisphere; this is consistent with the universalistic hypothesis that people share common perceptual structures, which lead to a similar color representation and a largely universal distinction between colors. At a certain point, however, the individual starts to receive the influence of his or her own culture, here specifically represented by linguistic labels; color names help toddlers to organize their perceptual experience and, in a way, to navigate the environment. Cultural processes and norms are, after all, the shared experience of a population and serve the individual as a guide for a successful life in his or her environment (see Kitayama & Cohen, 2010). One function of culture is to signal to its constituents what features to attend to, across the infinite possibilities of the environment, and to help them to group stimuli together according to these features. For colors, as for other stimuli, culture serves to direct individual attention in organized ways. When toddlers learn color terms, language seems to gain precedence over simple perception and sociocultural cognition starts to guide individual performance. Consistent with previous findings (Franklin, Clifford, et al., 2005), the bias does not change its phenotype (adults' categories are similar to infants' and toddlers' categories), but the underlying process seems to follow a different path. Indeed, the hemispheric predominance is shifted, suggesting an involvement of different brain circuits.

This hypothesis should be further tested but has already received some convergent support. For example, a more recent study (Zhou et al., 2010) has shown that even for adults it is sufficient to learn a color name to produce a new categorical perception of color, lateralized to the right visual hemifield. Moreover, Kwok et al. (2011) have shown an increase in the volume of the gray matter in the left visual cortex after adults learned new subcategorical color names; importantly, the area involved (V2/3) is known to mediate color vision.

Finally, other studies with toddler and older children have highlighted the influence of language acquisition in color perception. A study with toddlers between 2.5 and 4 years of age has found that language acquisition guides CCP in English and Himba speakers (Goldstein et al., 2009). The authors criticized previous estimations of toddlers' color term knowledge (Franklin, Clifford, et al., 2005) and assessed participants' linguistic abilities with more sophisticated methods. They found that only those toddlers who had a full comprehension of color labels showed categorical perception. Soja (1994) highlighted that, even though 2-year-old toddlers can already group stimuli based on color, they are still constructing their color categories connected to labels. Similarly, Roberson, Davidoff, Davies, and Shapiro (2004) showed a progressive categorical organization of colors alongside color terms acquisition. Finally, a study that assessed CCP in older children (4- to 7-year-olds) has brought more support to the relativistic hypothesis, showing cross-cultural differences between English and Namibian participants. Children showed a between-category advantage only when their culture possessed distinct color labels (Daoutis, Franklin, Riddett, Clifford, & Davies, 2006). Taken together, these findings suggest a new developmental perspective according to which several processes play different roles at various points in time, evolving from an initial sensory-based perception to a more culturally and linguistically mediated one.

To summarize, the developmental literature of color and race perception have shown parallel findings, with infants demonstrating similar behavioral perception to adults, thus leading researchers to embrace naturalistic theories (Franklin & Davies, 2004; Scott et al., 2007). In both literatures, moreover, labeling effects have also been highlighted (Goldstein et al., 2009; Scott & Monesson, 2009; see Appendices S3 and S4, for more details on the infants' and children's studies). However, although some developmental pathways have been identified in color perception (Franklin, Drivonikou, Clifford, et al., 2008), a clear evolution has not yet been established in race perception research. For this reason, in the following section we propose to bridge the two areas and hypothesize a common, though partially domain-specific, developmental mechanism underlying the evolution of both perceptual biases.

Color and Race: Two Sides of One Story? The Neurolinguistic Rewiring Hypothesis

Looking at the path of the two areas of research, namely the ORE and CCP, many similarities come to light. Although these two phenomena imply different kinds of effects, one attentive, the other mnemonic, studies in both domains make use of similar types of explanations and mechanisms and reveal parallel developmental paths. Based on previous findings in these domains, here we propose a new explanation of how categorical perception becomes progressively guided by cultural rules. We think it can account for the development of perceptual biases in those, and possibly other, domains of perception.

In the following section, we are going to explain our position by framing specific predictions and future research questions about a common evolutionary pathway between color and race perception. First, we argue that, in the adult literature of both research domains, perception is strictly linked to, and can be guided by, the linguistic and social framing of the categorical boundaries. Second, we hypothesize that infants' performance is not linked with linguistic framing, but it is instead drawn by the organization of the human visual system, although infants can form seemingly identical categories as adults. Third, extending the prior predictions, we hypothesize that a transition from a perceptual to a culturally guided cognition takes place with the exposure to labeling referents and linguistic training. During this passage, infants' brains are shaped and rewired by the connections to language areas. This neural shift does not necessarily change the phenotype, in the sense that the behavioral performance may remain the same as the previous developmental stages. However, the superimposition of language areas makes perceptual discrimination malleable and pliable by cognitive, social, and cultural influences.

To support our hypotheses, we have chosen to compare findings in two distant areas of research, color and race perception, because they represent two prototypical examples of perceptual biases, one concerning the physical and the other the social domain. Both effects involve biases in perceptual discrimination that are connected to the process of categorization. At first sight, the two phenomena appear very distant given that CCP implies a clear-cut distinction between elements of different categories, together with a homogenization of elements within the same category (Berlin & Kay, 1969), whereas the ORE concerns a memory bias for different types of faces (see Hugenberg et al., 2010). However, as argued by many researchers (see Rossion & Michel, 2011), the memory effect originates from a perceptual bias during the encoding stage. If one assumes that interracial memory bias is grounded in differential encoding, then the two phenomena become, indeed, quite similar. Moreover, there is considerable evidence that the recognition deficit derives from an asymmetrical face elaboration, with own-race faces being perceived in a more holistic and individualized way than other-race faces (Hugenberg et al., 2010; Scott & Monesson, 2009; Sporer, 2001; Young et al., 2012). People tend to group individuals of other races together and look at them only as representatives of their categories (e.g., Tanaka & Pierce, 2009). In this situation, the categorical perception seems to act in its general way, leading to a homogenization of the elements of the same category, just as it does for color perception. For members of the in-group, however, the process changes; due to experiential, social, and motivational factors, the group's constituents remain salient to the observer, who can easily distinguish between single individuals (Hugenberg et al., 2010).

Our first prediction is, therefore, that in both domains, ORE and CCP, the bias is influenced by culture as conveyed by linguistic labels. In the color perception literature, many experiments have shown that categorical perception is influenced by the color names present in a given culture (e.g., Athanasopoulos, 2009; Roberson et al., 2005), is lateralized to the left hemisphere (e.g., Gilbert et al., 2006; Liu et al., 2009; Mo et al., 2011), involves brain areas related to language (e.g., Siok et al., 2009), and is disrupted by verbal tasks (e.g., Roberson & Davidoff, 2000).

On the face discrimination side, studies highlighted that there are perceptual biases related to the in-group–out-group affiliation and that these groups could be arbitrarily created stressing different aspects of social identity. For example, the same ambiguous race faces are remembered differently depending on their assignment to the in group or to the out group (MacLin & Malpass, 2001; Pauker & Ambady, 2009), and the same faces are perceived more holistically (Michel, Corneille, & Rossion, 2010) and remembered better (Hehman et al., 2010; Van Bavel & Cunningham, 2012) when arbitrarily defined as in-group members. Also, other face recognition biases, for instance on the basis of age (Rhodes & Anastasi, 2012) and gender (Scherf & Scott, 2012), suggest a more generalized cognitive other-group effect (see Hugenberg et al., 2010), stressing the influence of socially defined categories rather than a different level of experience with faces.

Moreover, for face discrimination, direct effects of labeling have been found both in adults (Tanaka & Pierce, 2009) and in infants starting from 6 months of age (Scott & Monesson, 2009) suggesting an influence of language in the establishment of later performance. Specifically in this case, the labeling disparity for other- and own-race faces (only one categorical label linked to all other-race faces against many individual labels linked to each own-race face) seems, at least in part, to account for the difference in discrimination performance (Tanaka & Pierce, 2009). Combining all of these results, there appears to be a clear cultural influence on the perceptual performance in both domains, color and face perception.

Despite this preliminary evidence for linguistic labeling effects, further research on the linguistic influence on the ORE is needed. For example, we expect to find a direct relationship between language and categorical race perception, which should be reflected in the activation of linguistic brain areas and/or hemispheric asymmetry during race perception tasks. On the neurophysiological side, studies have highlighted a modulation of the N250 component by the race of a face (Balas & Nelson, 2010). This component has been linked to familiarity (Tanaka, Curran, Porterfield, & Collins, 2006) and to the subordinate category learning, which is usually conveyed by name labels (Tanaka & Pierce, 2009). From this perspective, it seems that own-race faces are linked to proper names, whereas other-race faces are linked to the category label. However, to our knowledge, no study to date has directly tested the neural link between language and race perception. Because we have hypothesized that language influences cognition by the recruitment of differential brain areas during the development, it is important to look at the brain underpinnings of these phenomena. Moreover, because in some cases the behavioral outcome is only partially affected by this cognitive shift (e.g., change in the predominant visual hemifield), the neural variable is fundamental to trace the developmental evolution of these biases.

Our second prediction concerns the perceptual nature of the ORE and CCP, in early infancy. In both areas, previous literature has demonstrated that discrimination performance of young babies is surprisingly similar to that of adults (Franklin & Davies, 2004; Sangrigoli & De Schonen, 2004a), supporting the view of the universal nature on these phenomena. In fact, the color categories (e.g., blue green, yellow red, blue purple) of infants of barely 4 months of age have been shown to correspond quite well to those of adults (Franklin & Davies, 2004).

Similarly, the ORE appears very early in the development, it has been shown in infants as early as 3 month of age (Kelly et al., 2005; Sangrigoli & De Schonen, 2004a). At birth, infants do not make any difference between faces of different races, so the bias should not be considered innate (Kelly et al., 2005). However, considering the early age, it becomes difficult to link infants' discrimination abilities to explanations other than the universal functioning of the perceptual system and mere perceptual experience (Scott et al., 2007). Even though the exposure to a particular group of faces could be seen as a social phenomenon, the expertise per se is a domain general effect that can be acquired with any kind of stimulus, and so it is not a specific social effect. It can be said that this process lays the foundation for the future establishment of stronger social phenomena linked with the in-group–out-group distinction.

In addition, in this case, more studies on the neural activation in response to race are needed. So far, few studies have tested the areas involved in race perception and, to our concern, only one EEG study has assessed other-race perception in 9-month-old infants (Balas, Westerlund, Hung, & Nelson, 2011). Results revealed that only own-race faces elicited the N290 component, an event-related potential linked to faces in infancy. This finding is consistent with the differential activation found in adults because the N290 is also more linked to familiar than novel stimuli (Scott & Nelson, 2006). Furthermore, it demonstrates that, already at 9 months of age, the brain responds differently to faces based on their ethnicity. However, we still do not know the nature of infant race discrimination. In this perspective, we have argued that the other-race discrimination bias is driven, in the infant population, by the perceptual distinction of the stimuli, together with greater exposure to same-race faces. Future studies are needed to compare the neural activation to race perception in infants and adults in order to establish whether different brain areas are recruited in these populations. Specifically, we expect to find brain areas connected to language to be activated during race perception tasks in adults but not in infants.

Our third hypothesis regards the ontogeny of these biases from pure perceptual to sociocognitive phenomena. The research and the findings of these two areas of research seem to follow two parallel, and rather similar, lines. Both, moreover, seem to encounter the same problems of explanation when it comes to tracing a complete developmental trajectory: Infants' and adults' results seem to support two antithetical theories, namely the universalistic and the cultural. In the field of color perception, however, some studies tried to shift the focus of research from the findings within a single population (adults or infants) to the developmental pattern. In particular, Franklin, Drivonikou, Bevis, et al. (2008) showed that, despite similar final outcomes, the processes that give rise to manifest CCP may be completely different, given that, when discriminating colors, infants use different brain areas than adults. Focusing on the evolution of the underlying mechanisms can therefore help to foster the comprehension of the phenomenon with all its seemingly incompatible displays; indeed, a dynamic picture can be created, explaining opposite effects at different ages in light of changed guiding mechanisms.

In particular, we argue that, as in the case of colors, in other-race perception a similarly evolving mechanism also takes place. It seems plausible to expect a similar developmental pathway because of the many comparable results found with respect to CCP and because of the fact that both the ORE and CCP are affected and can be manipulated by categorization. Again, as with color discrimination, infants seem to come to the same behavioral results by initially relying only on perceptual abilities. Therefore, it is plausible to suppose that the ORE also starts from a perceptual basis and only later becomes mediated by sociocultural factors. At the beginning, infants rely on their universal abilities to discriminate different colors and shapes. In this phase, a more prolonged exposition and a higher expertise with faces of the infant's own race could be the most important factor and the best predictor of good discrimination performance. As the infant grows older, the effect of cognitive factors should start to gain influence. In this phase, the culture could play a role in shaping both cognition and perception. The infant starts to have access to linguistic labels. His or her caregivers begin to present him or her many people (i.e., faces), accompanying them with phrases like "This is Uncle Jim," "She's Jane," and so on. The infant will reinforce his or her discrimination and mnemonic abilities thanks to the many individual labels to which he or she is exposed. For people of other ethnic groups, fewer experience together with a reduced number of available individual labels, the "out-group" label (e.g., "Asian" "African"), will progressively lead to a homogenization of these faces. The most important commonality with the CCP phenomenon would be the shift from a universal perceptual effect of discrimination, based on exposure, to a more cognitive and culturally driven one, based on socially shared linguistic labels.

Looking at the factors that foster this change in perception, moreover, the superimposition of cognitive categories over percepts seems to be the best candidate. Categorization is a well-documented, basic, and universal process of the human mind (Rosch, 1978) and even young infants show early categorization abilities (for a review, see Mareschal & Quinn, 2001). At the same time, categories are also highly susceptible to cultural influences, as they are malleable in relation to the specific circumstances (see Crisp & Hewstone, 2006). Culture and society can easily create various categories to stress particular boundaries of discrimination. Moreover, categorization and labeling are strictly linked to each other. In effect, labels make categories clearer and, in turn, categories help the language community, from which labels derive, to maintain a specific social system. The effect of labeling on perceptual discrimination has been already addressed in previous work on different areas such as face (Scott & Monesson, 2009) or object perception (Scott, 2011), and it has also been proposed as a top-down influence in the process of perceptual narrowing (Hadley et al., 2014).

Previous results of both research domains have highlighted a shift in cognition due to category labeling. In the ORE literature, recent studies showed that adults' (Tanaka & Pierce, 2009) and infants' face recognition performances (Scott & Monesson, 2009) are influenced by the level (categorical or individual) at which they learn the stimuli. Also in the domain of face perception, one may hypothesize that, due to repeated exposure, social categories start to arise, fostered and shaped by linguistic labels. This development makes in turn the bias to be modifiable by multiple categories as shown in the adult's literature (see Hugenberg et al., 2010).

Specifically, our neurolinguistic rewiring hypothesis states that the first linguistic effects concern the recruitment of differential neural circuits in the execution of the same task (e.g., stimuli discrimination). In the domain of color perception, studies have shown a shift in the predominant hemifield in toddlers that have learned color names (Franklin, Drivonikou, Clifford, et al., 2008). However, the same effect at the behavioral level was not found (Franklin, Clifford, et al., 2005) or was found only for children that reached a full comprehension of color names (Goldstein et al., 2009). In this perspective, after labeling training, we would hypothesize that there would be a different neural response to the categorical perception, connected to language neural circuits.

In the field of face perception, Scott and Monesson (2010) following their behavioral study investigated the neural bases of the individual-level training on other-species faces. They found a greater occipitotemporal inversion effect, corresponding approximately to the N290 and P400 components, for trained monkey faces. The authors argued that the individual-level training increases face holistic processing. A similar pattern of activation was found for individual-level training for objects (Scott, 2011). However, as far as we are aware, no study has directly tested the link between categorical perception of race and language, and the causal relationship between individual-level training and labels also remains unclear (see Scott & Monesson, 2009). In this sense, future studies are needed to explain how label learning affects the recruitment of different brain areas in infants or young toddlers.

Studies with children in both ORE and CCP, moreover, have produced results that are consistent with the neurolinguistic rewiring hypothesis. In our perspective, after language learning, children should progressively show similarities to the adult population, in the sense that perceptual biases should progressively become linked to sociolinguistic categorization. In the field of color perception, the few studies that have tested child participants have, in fact, found linguistic influences on CCP (Daoutis et al., 2006; Roberson et al., 2004). In the face discrimination literature, many studies have found a consistent ORE in toddlers of 3 years of age (Pezdek et al., 2003; Sangrigoli & De Schonen, 2004b; Suhrke et al., 2014). Moreover, although some findings seem to point to a greater reliance on perceptual cues in 4- to 6-year-old children than in adults (Balas et al., 2015), Shutts and Kinzler's (2007) study found that, at 3 years of age, the ORE is already susceptible to the social modulation of the categories. These results seem to support an early influence of linguistic labels on later perceptual biases. However, other studies have found an increase in the strength of the ORE as late as 5–8 years of age (Chance et al., 1982; Goodman et al., 2007). These results can be explained by a difference in the exposure to categorical labeling for these children. If the ORE is connected with a differential level of categorical training (individual vs. category labeling) between own and other races, it could be hypothesized that some infants or toddlers have been, instead, exposed to a similar amount of individual-level labels for both own- and other-race faces. These children, therefore, may have not yet developed a stable ORE. In this perspective, an interesting future direction would be to investigate the long-term effects of early exposure to different category-level training with faces, in order to assess whether the association of other-race faces to individual labels may prevent the development of the ORE.

Although we propose that the ORE and CCP are guided by the same principles and show a similar developmental trajectory, we should also clarify that the two areas are to some extent distinct. The phenomenon of face perception is immersed in the social domain and, hence, more likely to be influenced by social and cultural factors. In this respect, it is important to point out the peculiarities of social perception. One important variable that must be taken into account for racial distinction is the stronger motivational factors that favor the in group (see Hugenberg et al., 2010). Although in color perception the different categories (e.g., blue, green, red) do not hold particular meanings and have the same level of salience, social categories symbolize social meanings, are part of a social hierarchy, and have different personal relevance for the individual. A direct consequence of this is the differential treatment of the elements of different categories (e.g., the holistic vs. analytical elaboration), which in turn leads to different behavioral outcomes (better recognition of the elements of one category). Thus, although color perception operates in a symmetrical fashion for any color label of the spectrum, the ORE is, per definition, asymmetrical, favoring memory for one's own race over another. In both domains, there is a tendency to exaggerate within-category similarities as well as between-category differences; however, only in the case of ORE will people be personally part of one of the two groups, resulting in an asymmetrical memory bias. People are exposed to individual labels for each own-race face. This may help them to discriminate these stimuli in much the same way, in which the category labels help to discriminate entire categories.

Another example of a stronger influence of sociocognitive processes on face elaboration is represented by biases in the perception of intercategorical boundaries: Although Levin (2000) has shown that race is perceived in a categorical manner and people tend to exaggerate between-category differences, there is also evidence that some effects are driven by social categorical learning. An exemplificative phenomenon is the hypodescent effect, which induces people to categorize mixed-race faces to the minority group (Halberstadt et al., 2011). As a result, the interracial cutoff almost never lies on the real perceptual boundary, but instead there is an overexclusion for the majority group and an overattribution to the minority. This effect highlights how racial categories are much more fluid than color categories and also how motivational and social factors may come into play, biasing the simple perceptual process.

This differential treatment of the categories is probably the most fundamental difference between the two domains. Although color perception concerns objects, typically as part of the physical environment, the other-race perception, even if it implies to some extent color perception, is a social cognitive phenomenon. It is therefore reasonable to assume that, in the latter case, cultural rules play a more important role, as they generally regulate human interactions (Kitayama & Cohen, 2010). Thus, more than any other domain, race-based perception should be shaped by sociocultural variables such as social identity and stereotypes. In this sense, linguistic labels may exert a much stronger influence in shaping social rather than physical categories and perception. In this respect, we hypothesize that the effect of linguistic labels may appear earlier in the developmental pathway (see Scott & Monesson, 2009).

Conclusion and Future Research

To summarize, color discrimination, as an example of categorical object perception, and the ORE, as an example of face recognition bias, share similarities in both their developmental trajectories and in their theoretical accounts. Because in the field of CCP an important achievement was reached by shifting the focus of research from an adult model to a developmental perspective, we believe that a similar parallelism would also foster a broader comprehension of the process behind the ORE. We propose here to look for a more general developmental mechanism able to account for this cross-domain (color and race perception) shift from perceptual to a more cognitive knowledge of the environment. Specifically, we argued that, at the beginning, in their discrimination, infants are driven by the perceptual differences in the stimuli. Later on, with the introduction of label–stimuli coupling we argue that language starts to influence the neural pathways involved in categorization and perception. In the domain of color perception, this effect has already been shown (Franklin, Drivonikou, Bevis, et al., 2008), whereas in the domain of ORE, this hypothesis has not yet been directly tested. However, results on the effect of categorical and individual labels on face recognition (Scott & Monesson, 2009; Tanaka & Pierce, 2009) encourage thinking that there could be a similar developmental mechanism. We also hypothesized that in later developmental stages and in adulthood, perceptual biases become driven by the sociolinguistic categorization of the stimuli. Importantly, we also argued that the social domain would be more strongly influenced by linguistic labels than physical ones.

To trace a link between color to face discrimination, future research should respond to a number of critical empirical questions. First of all, the brain areas involved in this process need to be identified in both domains. As highlighted by Franklin, Drivonikou, Clifford, et al. (2008), there is a shift in the visual hemifield predominance of categorical perception at the time children learn new category labels. Although studies with adults have shown an involvement of language brain areas in color perception (e.g., Siok et al., 2009), the hypothesis that there are specific and different neural networks involved in color perception before and after children learn color names has not been directly tested.

In the field of face perception, moreover, studies have highlighted the presence of a cortical network for face perception that involves many different regions, including the occipital gyrus, the lateral fusiform gyrus (FG), the inferior frontal gyrus, the superior temporal sulcus, along with other brain areas such as the amygdala, the insula, the nucleus accumbens, and the orbitofrontal cortex (Ishai, 2008). The most studied brain area in face perception, nevertheless, is a part of the FG, called the fusiform face area (FFA; for a review, see Kanwisher & Yovel, 2006). There is considerable debate about the purpose of this area. The main two perspectives claim, respectively, that (a) the FFA is domain dependent and is specialized for face-like stimuli or (b) that FFA is process dependent and specialized for fine grade discrimination and within-category stimuli individuation (McKone & Robbins, 2011). In both cases, the functioning of this brain area is interesting, as it seems connected to the processing of own-race faces. Moreover, effects of a lateralized activation in response to race have been found. An fMRI study comparing activation for own and other-race faces highlighted two different patterns of activation for the two groups (Golby, Gabrieli, Chiao, & Eberhardt, 2001). The authors found a larger activation for own-race faces in the right FFA, a finding that is consistent with previous results on brain activation in face perception (Golby et al., 2001). At the same time, these authors also found a positive correlation between left FFA activation and face recognition performance. They hypothesized that "left hemisphere pathways may mediate categorical visual processes that maximize similarities among examples in a category, whereas right hemisphere pathways may mediate coordinate visual processes that maximize individuation between examples in a category" (Golby et al., 2001, p. 847). The hypothesis of Golby and collaborators locates the categorization process in the left hemisphere (see also Feng et al., 2011). This claim seems to be consistent with the findings for color discrimination, where the process of categorical perception is lateralized to the left hemisphere (Gilbert et al., 2006). Moreover, another study has also found a modulation of the social categorization of faces in the FFA. This region had a larger response to faces, which were arbitrarily categorized as in-group faces (Van Bavel, Packer, & Cunningham, 2011). At a behavioral level, studies have shown an opposite left visual hemifield bias in face perception (Balas & Moulson, 2011), which is only present for in-group faces (Correll, Lemoine, & Ma, 2011). These results speak only to the activation for within-category stimuli while being silent as to cross-category boundaries in racial perception. Thus, it still remains to be investigated whether there is a categorical race perception that is lateralized to the left hemisphere in adult individuals. Even if this was the case, this would leave open the most interesting research question, namely when this lateralization appears and in relation to which specific actors.

The second element to disentangle is the time at which labeling driven categories start to influence face race perception. The only study that has investigated the effects of labeling on the establishment of an other-group effect found the first evidence for the influence of language on this bias between 6 and 9 months of age (Scott & Monesson, 2009). This is a very early developmental stage, especially when compared to CCP, where the effect of labels starts to emerge only between 2 and 5 years of age (Franklin, Drivonikou, Clifford, et al., 2008). This timing discrepancy may be attributed to the different domains of experience. Although face perception concerns the social environment and the face is arguably the most important stimulus for the infant, color is likely to be less critical for the survival of infants. Face is also a recurrent object in the baby's visual field for the first months of life and infants become early expert face processors (Pascalis et al., 2011). Probably due to a greater exposition and emphasis, the appraisal of face elaboration progresses faster than the development of other abilities. In this respect, future studies should assess (a) when labeling training starts to produce an effect on infants' perception, (b) which subtending neural mechanisms are underlying the labeling effect, and (c) how much training is necessary to produce a long-term effect.

Finally, it is important to remember that face perception is affected also by other sociocognitive factors such as the valence connected with social categories. In fact, categorical differentiation of human groups implies disparities in valence, status, stereotypes, and in-group favoritism. In-group favoritism has been found in children starting at around 3 years of age (Carraro & Castelli, 2015) so, at least at that time, they recognize the difference between the in group and out group, and they can assign positive and negative evaluations to different ethnic groups. It becomes, therefore, important to disentangle the relation of these factors with the ORE and, in particular, with the labeling effects discussed earlier. What is the relationship between the ORE and the in-group favoritism? What role does the labeling play in the emergence of in-group favoritism and stereotypes, and how do these, in turn, relate to ORE? It becomes important to investigate whether the labeling referent brings to the object, together with the name, also an association with a specific value or stereotype since early infancy or whether later processes shape a more structured semantic map around the preceding category label. In this respect, future studies should identify the developmental pathways that link the ORE to out-group stereotyping and in-group bias.

In summary, here we have proposed to look at the similarities between two domains of human perception: one concerning the physical and the other the social environment. These two areas share many similarities and many common questions. We propose to bring together these issues and the results achieved so both can benefit from the breakthroughs of the other. Moreover, we think it could be important to look at a common developmental mechanism that shifts human cognition from a perceptual to a cognitive and socially mediated vision of the world. In this regard, the neurolinguistic rewiring hypothesis proposes the effects of labeling in shaping the underlying neural pattern subtending categorization and perception. This hypothesis should be analyzed deeper and within a broader spectrum of phenomena in order to understand how much different domains of perception and cognition share the same process or, instead, how much every area develops its own specific processes due to domain-specific variables. Far from claiming that this factor could explain all developmental changes in biases of perception, we think that is desirable to identify the most parsimonious and generalizable patterns in the evolving of human cognition, without losing sight of the peculiarities of each domain.

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