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The influence of memory on perception: It's not what things look like, it's what you call them

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World knowledge influences how we perceive the world. This paper shows that this influence is at least partly mediated by declarative memory: Dutch and German participants categorized hues from a yellow-to-orange continuum on stimuli that were prototypically orange or yellow and which were also associated with these color labels. Both groups gave more yellow responses if an ambiguous hue occurred on a prototypically yellow stimulus. The language groups were also tested on a stimulus (traffic light) that is associated with the label "orange" in Dutch and with the label "yellow" in German, even though the objective color is the same for both populations. Dutch observers categorized this stimulus as orange more often than German observers, in line with the assumption that declarative knowledge mediates the influence of world knowledge on color categorization.

Introduction

Observers tend to perceive the world in accordance with their expectations. A yellow-orange hue is more likely to be categorized as orange on a carrot than on a banana (Mitterer & de Ruiter, 2008). A face is perceived to be lighter if it contains prototypical "white" features rather than "black" ones (Levin & Banaji, 2006). A speech sound that could be /t/ or /d/ is perceived as /d/ in "?ash" but as /t/ in "?ask" (Ganong, 1980; Warren, 1970). A slightly ambiguous letter—such as an "H" in which the two vertical lines are tilted inwards—is perceived as "A" if it occurs in "C?T" but as "H" if it occurs in "T?E" (McClelland & Rumelhart, 1981). These object-based biases are useful for the observer, because perceptual evidence in the real world tends to be less than perfect. The light reflected from a banana depends strongly on the lighting source, speech sounds can be masked by ambient noise, and careless handwriting can blur the distinctions between different letters. When faced with ambiguity, the observer is going to be right more often than wrong when assuming that a banana really is yellow—at least when in a supermarket.

There is a long-standing debate whether such biases show a top-down flow of information. Undoubtedly, an interactive activation and inhibition account elegantly explains how we perceive the world in line with world knowledge (McClelland & Elman, 1986; McClelland & Rumelhart, 1981). The two left panels in Figure 1 show such an architecture. Information from perception is fed forward to memory and the content of memory then directly influences how the stimulus is perceived. Consider the "?ash" vs. "?ask" example above. The words *dash* and *task*, respectively, best fit the perceptual evidence because *tash* and *dask* are not words in English. Lexical activation from the real words feeds back to the phoneme-perception units, which then boosts activation for the /t/ unit when the input is "?ask", which in turn inhibits the /d/ unit. As a consequence, /t/ is more strongly activated than /d/ in response to the stimulus "?ask". This explains why listeners hear a /t/ more often in "?ask"

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than in "?ash". Such top-down feedback may help us overcome the immense variability that we face in perception, like the invariance problem in speech perception (Liberman, 1996) or the color-constancy problem in visual perception (Brainard, 2004).

Skeptics have, however, argued that feedback from a lexical to a pre-lexical level is not necessary to explain how world knowledge biases perceptual categorization (Massaro, 1998; Norris, McQueen, & Cutler, 2000). According to this alternative account, when a listener is confronted with input such as "?ask", he or she just has to weigh the perceptual evidence (which is ambiguous) against the lexical evidence (which indicates a /t/), to arrive at the decision that there was a /t/ and not a /d/ in the input. That is, the perceptual and the world knowledge are merged to arrive at a perceptual decision. This alternative model is depicted in the two right panels of Figure 1. Note that there is no direct feedback from memory on perceptual processes. In support of this view, Frauenfelder and Peeters (1998) found that top-down feedback is—in contrast to the general intuition—not a useful tool for perception to overcome the variability that perception faces. They showed that an interaction-activation model of word recognition (TRACE, McClelland & Elman, 1986) works just as efficiently when top-down connections are removed.

In order to distinguish these two accounts—feedback to perceptual encoding vs. merging at perceptual decision—recent research has moved to procedures where recruitment of explicit knowledge is thought unlikely to be involved, thus potentially ruling out a merging account. For example, in color perception, Hansen, Olkkonen, Walter, and Gegenfurtner (2006) asked participants to change the hue of an object—by pressing one of four buttons which increased or decreased the hue values in a two-dimensional color space—so that it appeared gray to them. In contrast to a simple categorization task ("Is this object yellow or orange?"), this task does not necessitate access to color labels. For objects without a prototypical color, participants performed quite well and found an objective achromatic hue. But for objects with a prototypical color participants chose a hue that was opposite to the object’s natural hue, so that the color of a banana was changed to a slight bluish-gray instead of a truly achromatic gray hue. This indicates that a banana that is objectively gray actually appears slightly yellow. Although this task does not necessitate recruitment of color labels, it is possible that they are nonetheless activated. It appears that activation of object concepts also activates knowledge of their color. For example, hearing the word "banana" activates the concept "yellow" (Huettig & Altmann, 2004). Likewise, it is probable that on seeing a banana the concept "yellow" is also activated. So it is quite possible that declarative knowledge about object color influenced perceptual decision-making without influencing perceptual encoding.

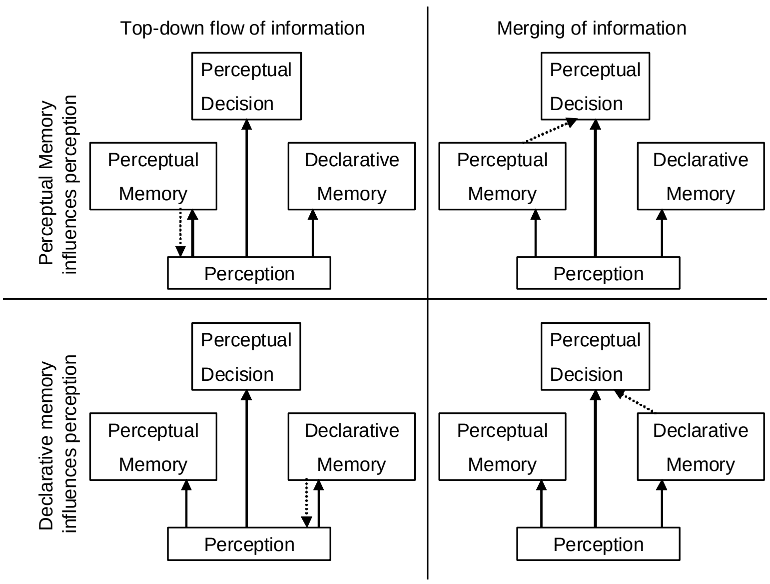

Figure 1. Four ways of accounting for the influence of memory on perception. The solid arrows show uncontroversial flow of information, and dotted arrows show controversial connections.

A different sort of indirect task has been developed in speech-perception research. Phonetic research has shown that in comparison to an unambiguous /sh/, an unambiguous /s/ makes a following stop sound more like /k/ (rather than /t/) (Mann & Repp, 1981). In addition, an ambiguous sound between /s/ and /sh/ is perceived as /sh/ in *fooli*? and as /s/ in *christma?*. So the question becomes whether lexically induced percepts of /s/ and /sh/ influence the perception of a following stop as either /t/ or /k/ just as the signal-based percepts of unambiguous /sh/ and /s/ do. This would be predicted by a feedback to perceptual encoding account. While there are some positive findings (Elman & McClelland, 1988; Magnuson, McMurray, Tanenhaus, & Aslin, 2003; Samuel & Pitt, 2003), there is still some doubt that these findings show top-down feedback (McQueen, 2003; McQueen, Jesse, & Norris, submitted; Mitterer, 2007).

The studies summarized above—and in fact most of the existing literature—have focused on questions about information flow, that is, whether higher-level information directly influences perceptual processing. There is, however, a related—though logically separate—issue: What kind of information mediates such object-based biases? Or to put it another way, is the influence of world knowledge on perceptual categorization mediated by declarative or perceptual memory? It has long been accepted that human memory is not a unitary system, but that there are different forms of memory, including perceptual memory about how things look and sound and declarative memory, such as the knowledge that bananas are called "yellow" (e.g., Blaxton, 1999; Squire, 2004). The question we address is which of these two memory systems is implicated in object-based biases. In the "?ask" example, is it abstract phonological knowledge that can be consciously entertained, (e.g., that the word *task* starts with the same phoneme as the word *town*), or is it the perceptual knowledge about what type of sound precedes "?ask", that is, knowledge that this sound tends to be a high-frequency (in Hertz), high-amplitude burst. In the color domain, does a banana appear more yellow than it actually is because we know (declaratively) that "bananas are yellow", as depicted in the two lower panels of Figure 1? Or do we assume that the hue on this banana is probably similar to the hues we (perceptually) remember from encounters with other bananas, as depicted in the upper panels of Figure 1?

The conundrum is that these two potential factors—declarative and perceptual memory—are (nearly) perfectly correlated: The perceptual memories of typical bananas correlate with the verbal label that participants use to describe bananas. This is probably why—as far as we are aware—previous research has not attempted to tease apart the influence of these different forms of memory on perception. Nevertheless, we identified a situation in which the two factors can be separated: traffic lights in Germany and the Netherlands. The topmost and bottommost colors of traffic lights are described with the cognate color terms for "green" and "red" (German: *grün* and *rot*; Dutch: *groen* and *rood*), but the middle light is subject to variation: Germans use their equivalent of “yellow” (i.e., *gelb*), and the Dutch use the term for their national color “orange” (i.e., *oranje*). This diversity arises even though the perceptual memories (at least of typical undergraduates) must be similar, because traffic lights in the European Union are bound by a European norm (EN 12368 Deutsches Institut für Normierung, 2006). This situation allows us to tease apart the contributions of perceptual memory and verbal labels on perceptual decisions.

In line with previous work investigating the influence of world-knowledge on perception ,we created a continuum of hues ranging from a good yellow to a good orange (Ganong, 1980; Levin & Banaji, 2006; Pitt & McQueen, 1998; Samuel & Pitt, 2003). These hues were then used to color the middle light of a traffic light, and observers were asked whether the hue was "yellow" or "orange". If German participants call the hues on the middle traffic light "yellow" more often than Dutch participants then the object bias in color perception stems from declarative knowledge since Germans call this object *gelb* (English: *yellow*), while the Dutch call it *oranje* (English: *orange*). If, however, perceptual memory of traffic lights induces the object bias in color perception, the two groups should not differ in their yellow responses since they have similar exposure to traffic lights.

There is a caveat to this prediction. The color categories of Dutch and German may not be identical, even though nearly all color terms are cognate in the two languages. Several recent papers have shown that color perception and processing is not completely determined by (physiological) universals (Roberson, Davies, & Davidoff, 2000; Winawer et al., 2007). So a difference between Dutch and German observers in the number of "yellow" responses to hues displayed on a traffic-light would not necessarily indicate different labeling of the traffic-light colors, but could be to a difference in the color categories of yellow (Dutch: *geel*, German: *gelb*) and orange (Dutch: *oranje,* German: *orange*) instead. To forestall this possibility, we included a color-neutral stimulus (a sock) which was colored in the same hues as the traffic light. If the color categories differ between the groups for our stimuli, this should lead to a group difference for both the sock and the traffic light stimulus. On the other hand, if a group difference is only observed for hues on the traffic light stimulus, a misalignment between Dutch and German yellow and orange categories cannot account for the data.

In addition to the sock, we also included a prototypically orange stimulus (a carrot) and a prototypically yellow stimulus (a banana) in order to replicate the object bias effect in color categorization. If both Dutch and German participants give equivalent yellow responses to the traffic light and both groups give more yellow responses to the banana than to the carrot, we have strong evidence that the object bias in color categorization is caused by perceptual memory. If instead Dutch and German participants give different color responses to the traffic light, then the object bias in color categorization is (at least in part) due to declarative memory.

Method

Participants

Thirty-nine volunteers participated in the study. All had normal or corrected to normal vision and reported no color-perception impairments. Twenty were native speakers of German studying at the RWTH Aachen University, Germany. Nineteen were native speakers of Dutch from the subject pool of the Max Planck Institute for Psycholinguistics, the Netherlands.

Materials and Procedure

All experiments were run in a completely darkened room with a 15 inch LCD monitor (Iiyama TXA3823MT) as the only source of light. We generated a continuum of six hues from yellow to orange. The CIE (Commission internationale de l'éclairage) XYZ coordinates of these hues were: hue 1: [60.0, 53.8, 8.5], hue 2: [61.4, 57.4, 9.0], hue 3: [63.9, 60.3, 9.4], hue 4: [65.7, 64.3, 10.2], hue 5: [67.6, 67.6, 10.8], hue 6: [69.8, 71.5, 11.5]. These hues were then placed on four different pictures (see Figure 2): a traffic light with the middle light being "on", a sock, a banana, and a carrot. These four pictures and six hues led to 24 experimental stimuli. These stimuli were presented to the participants with the Presentation® software (Version 11.26, www.neurobs.com).

Participants were tested individually facing the computer screen. They were instructed to categorize the color on the objects as yellow or orange by pressing the corresponding response button. They were then presented with 15 blocks in which the 24 experimental stimuli were each presented once. Within each block, the stimuli were randomly permutated.

Design and Analysis

In this experiment, we tested to what extent the proportion of yellow responses is influenced by the hue, the object identity and the native language of the observer. Given the categorical nature of the dependent variable, we used a linear-mixed effect model with a logistic linking function (as suggested by Jaeger, 2008) to predict the proportion of yellow responses with the factors hue, object, and native language of the observer as fixed effects, and observer as a random effect.

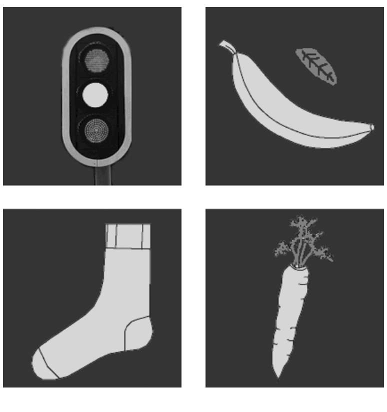

Figure 2.
The four stimuli used in this experiment.

Results

Figure 3 presents the results as the percentage of yellow responses. There is a tendency for the Dutch participants to give more yellow responses to all objects but the traffic light. The statistical analysis accordingly shows—besides the trivial effect of hue—an overall interaction of Object by Native Language ($F(3, 13939) = 8.59$, $p < 0.001$)[1].

We therefore ran separate analyses for each object, which showed no effect of Native language for the objects carrot, banana, and sock ($p > 0.1$). There was, however, a significant effect of Native Language for the traffic light ($b_{(Language\ =\ Dutch)} = 0.51$, $p < 0.05$). We examined whether the influence of Native Language differed between the steps by introducing a hue by Native Language interaction, which was not significant (p> 0.1). This may seem surprising, given the small difference for the most yellowish hues, but it is important to remember that small differences near the margins of a proportional scale are (correctly) inflated by the logistic-regression method (cf. Jäger, 2008).

Disregarding the language variable, we find that there are more yellow responses across the hues if the hues are on the banana than if the hues are on the carrot." ($b_{(Object\ =\ banana)} = 0.47$, $p < 0.001$) and that there are more orange responses if the hue is on the sock than if it is on the carrot ($b_{(Object\ =\ sock)} = 0.29$, $p < 0.001$).

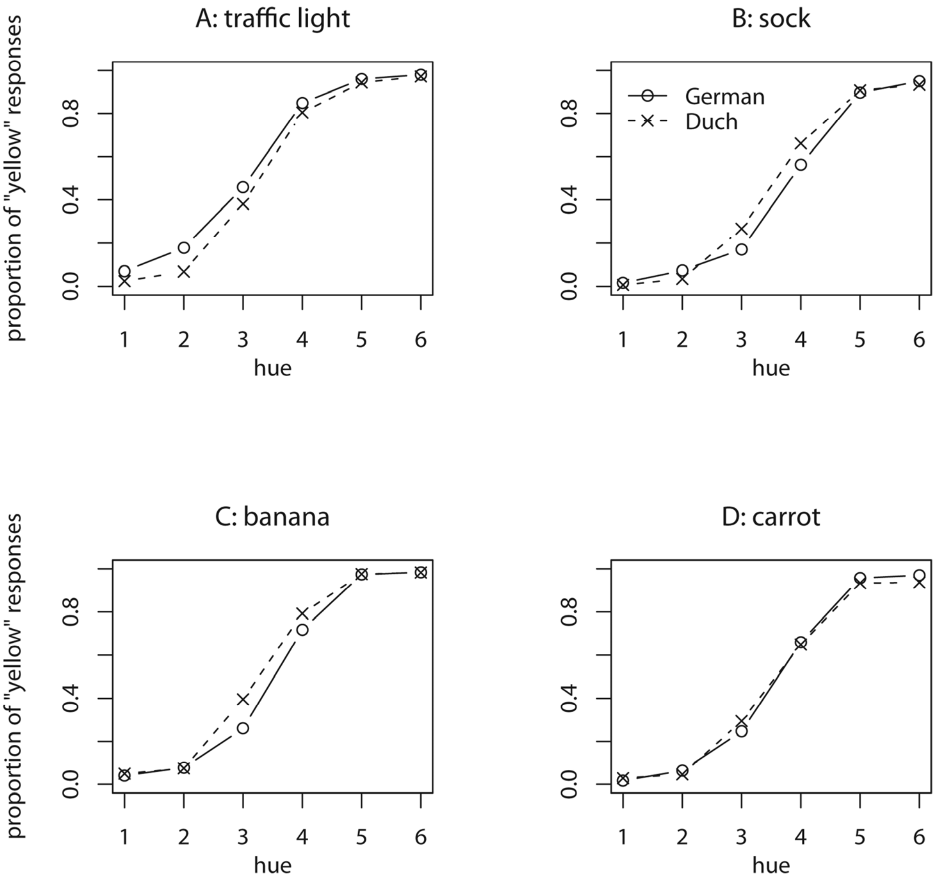

Figure 3. The proportion of yellow responses for the two groups of participants (different lines) depending on the hue (x-axis) and the presented objects (different panels).

[1] As the large number of degrees of freedom indicates, the statistical method uses every single data point (39 participants times 24 pictures times 15 presentations). It is, however, not a simple logistic regression, which would fail to take into account that some of the data points are not independent (i.e., those coming from the same participant). Baayen, Davidson, and Bates (2008) show that despite the large number of degrees of freedom, the mixed-effect models are not prone to yield Type I errors.

Discussion

In this experiment, we tested whether the influence of world knowledge on perceptual categorization is caused by declarative or perceptual memory. It was possible to tease these factors apart because Dutch and German observers differ in their declarative, but not perceptual memory for traffic lights: Traffic lights are bound to European regulations in both countries, but the Dutch call the middle light *oranje* (orange), while the Germans call it *gelb* (yellow). German observers categorized hues applied to the middle traffic-light as yellow more often than Dutch observers, while there were no significant differences between the groups in color categorization for other objects. The difference in declarative memory for traffic lights is the most likely cause of this result.

There were two additional findings, one expected one unexpected, that are independent of native language. Both Dutch and German participants gave more yellow responses to a banana than to a carrot, in line with the world knowledge that "bananas are yellow" and "carrots are orange". It was unexpected, however, that the sock object induced even more orange responses than the carrot. One explanation for this finding is a possible difference in simultaneous brightness contrast. Yellow is in general a brighter color than orange. The objects were displayed on a dark gray background, which make their boundaries appear brighter. Because the sock was the largest object in the line drawings we used (see Figure 2), this contrast contributes a little less to its overall appearance than it does for the slender carrot, which may therefore appear brighter and more yellow than the sock.

However, this possible effect of simultaneous contrast cannot be the cause of the main result of this experiment: the difference in yellow responses between Dutch and German observers for the traffic light stimulus. The picture was, after all, the same for both groups of observers. Could there be yet another explanation for the observed difference between the groups? One possibility is that color boundaries between yellow and orange differ between the two groups. We ruled out this possibility by including non-traffic-light objects. Any differences in color boundaries would have influenced the responses on the other objects as well, but there we do not find a difference between the two groups.

The current results seem to indicate that declarative knowledge and not perceptual knowledge leads us to perceive the world in line with our expectations. This is consistent with previous findings suggesting that the perception of color relies on actively naming these colors: Participants judge two colors from the same linguistic category to be more similar to one another than stimuli from different linguistic categories (a categorical perception effect). Crucially, when the boundaries of color categories vary across languages, performance is determined by language-specific categories rather than perceptual distance (e.g., Roberson et al., 2000). While these effects by themselves could be mediated by a language-induced top-down reorganization of the perceptual space, several recent findings show that these effects may instead be mediated by an active recruitment of color labels. Categorical perception is stronger in the right visual field than in the left visual field (Drivonikou et al., 2007; Gilbert, Regier, Kay, & Ivry, 2006; Roberson, Pak, & Hanley, 2008). This implicates an active role for verbal labels, because the right visual field is projected to the left hemisphere, in which most lexical knowledge is stored. Moreover, under verbal – but not spatial – interference, categorical perception of color disappears (Gilbert et al., 2006; Roberson & Davidoff, 2000; Winawer et al., 2007). Taken together, these findings suggest that declarative memory has a crucial role to play in perceptual decision-making.

Obviously, we cannot rule out that perceptual memory has a role to play as well. Nevertheless, the current data indicate that this role may be rather minor. As it turns out, the effect of object identity (banana vs. carrot) is very similar in size to the effect of language-specific labeling for the traffic light stimulus. Both effects are around 5% in the descriptive data, leading to a change of 0.5 in the log(odds) in the statistical model. Hence, a labeling bias is sufficient to explain the observed numerical difference in yellow responses to the banana and carrot.

We have argued that verbal labels mediate the influence of world-knowledge on perceptual decision. In doing so, we contribute to the lively debate concerning the extent to which language can shape thinking and perception (Davidoff, 2001; Davidoff, Goldstein, & Roberson, 2009; Franklin, Wright, & Davies, 2009; Goldstein, Davidoff, & Roberson, 2009; Kay & Regier, 2006; Levinson, Kita, Haun, & Rasch, 2002; Li & Gleitman, 2002; Majid, Bowerman, Kita, Haun, & Levinson, 2004). At first sight, our results are clearly encouraging for a Whorfian view by showing that simply calling an object "yellow" or "orange" influences how hues on these objects are categorized. This dovetails well with the other recent findings of color naming on color perception cited above, which also indicate that verbal labeling influences color perception. However, the Whorfian view often implicitly assumes an effect of language on perceptual encoding, rather than on perception decisions. The merge model (Norris et al., 2000), which does not postulate an influence of world knowledge on perceptual encoding, is nevertheless sufficient to explain many Whorfian effects. Consider Winawer et al. (2007), who showed that Russian observers are faster to discriminate two hues if they are named differently. The merge architecture predicts this result, as the "different" response is suggested both by the perceptual evidence and by declarative knowledge, which leads to a faster response time than when declarative knowledge suggests a conflicting "same" response. If verbal interference prevents declarative knowledge from exerting an influence, only perceptual evidence drives responses, and the effects of language-specific color categories should disappear, as they do in the empirical data.

When putting forward a merge-type architecture, we do not meant to trivialize the influence of language on perceptual tasks. In line with the Bayesian view on perception (e.g., Norris & McQueen, 2008), we think that it is crucial to use prior knowledge in interpreting the world is crucial. The framework still allows for language to influence how we interpret and react to the world in an on-line and interactive manner in line with the claim of Winawer et al. (2007). But this influence does not overwrite perceptual evidence. As Norris et al. (Norris et al., 2000; Norris, McQueen, & Cutler, 2003) pointed out, this is beneficial for optimal perception, because world knowledge can then be used to overcome the inherent ambiguity in perception, not only for a given stimulus, but also for the functional recalibration of categories. Several recent papers have shown how higher-level knowledge is used to recalibrate perception, for example, when there is a mismatch between expected and observed perceptual information (Mitterer & de Ruiter, 2008; Norris, Butterfield, McQueen, & Cutler, 2006; Norris et al., 2003; van der Linden & Vroomen, 2007). If perceptual information were to be overwritten, the mismatch between expected and observed information would go unnoticed, and no recalibration could occur.

To conclude, we set out to investigate whether declarative knowledge alone is able to influence perceptual decisions. Our data showed that it can. Moreover, our data indicate that perceptual knowledge may not have an independent contribution to object-based biases in perception. However, to conclusively demonstrate this, future research needs to explore situations that are the mirror-image of the one investigated here, where perceptual memory differs between groups but declarative knowledge remains the same.

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