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Language-induced categorical perception of faces?

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Language-induced categorical perception of faces?

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Abstract

Categorical perception (CP) facilitates the discrimination of stimuli belonging to different categories relative to those from the same category. Effects of CP on the discrimination of color and shape have been attributed to the top-down modulation of visual perception by the left-lateralized language processes. We used a divided visual field (DVF) search paradigm to investigate the prospective effects of CP for face identity and gender processing. Consistent with visual processing of face identity in the right hemisphere, we found CP facilitated perception only in the left visual field (LVF). In contrast, and consistent with language-induced CP, we observed a between-category advantage for processing face gender only in the right visual field (RVF). Taken together, our results suggest that language-induced CP plays a role in the category-based visual processing of faces by the left hemisphere, but face familiarity processing might be dependent on different, identity-specialized networks in the right hemisphere.

Keywords: categorical perception, face processing, lateralization

Introduction

Stimuli that vary continuously (e.g., wavelength) are sometimes perceived as having categorical boundaries (e.g., color). In some cases, *categorical perception* (CP) is thought to facilitate the discriminability of stimuli belonging to different categories (e.g., wavelengths seen as either "blue" or "green") as compared to those belonging to the same category (e.g., different wavelength but each seen as "blue"), even when physical differences between stimuli are equivalent (Goldstone & Hendrickson, 2009). Effects of CP on visual processing are often explained as due to top-down language modulation (as discussed in Simanova et al., 2015)—*language-induced CP*—and have been reported to facilitate the discrimination of color, shape, motion, and other visual modalities (Biederman & Shiffrar, 1987; Holmes et al., 2009; Meteyard, Bahrami, & Vigliocco, 2007; Sowden & Roling, 2000; Winawer et al., 2007). Despite extensive work in the domain of language-induced CP and visual perception, most of the studies focus on simple visual stimuli. Here, we investigate whether CP also influences processing of complex visual stimuli, such as faces.

Language processing and visual processing of linguistic stimuli (e.g., words) are typically lateralized to the left hemisphere (Dehaene-Lambertz et al., 2002; Wada, Clarke, & Hamm, 1975). In contrast, visual processing of faces is associated with the right hemisphere (RH) superiority, based on the findings from neuroimaging (Kanwisher, McDermott, and Chun, 1997; Rotshtein et al., 2005) and the *divided visual field* (DVF) experiments (Dundas, Plaut, & Behrmann, 2013; Hilliard, 1973; Ossowski and Behrmann, 2014; Rizzolatti, Umiltà, & Berlucchi, 1971). In the DVF experiments, observers view stimuli presented either in the right (RVF) or the left (LVF) visual fields. This paradigm capitalizes on contralateral hemifield-hemisphere correspondence in the human visual system (RVF stimuli are projected directly to visual cortex in the LH and LVF stimuli to the RH). The DVF paradigm has also been used to study the visual processing of linguistic stimuli, as well as language-induced CP during the visual processing of non-linguistic stimuli.

Gilbert et al. (2006) used a *DVF search* paradigm to explore the language-elicited CP effect on color perception. They presented observers with color stimuli in the left the right visual hemifields. All stimuli were identical except for the one target stimulus, an "oddball" (of a slightly different wavelength). On each trial, oddball stimulus belonged to either a different color category than the "distractor" stimuli (e.g., green among blue stimuli) or the same color category (e.g., a saturated blue among less saturated blue stimuli). Critically, oddball target and distractor stimuli always differed by the same wavelength regardless of whether they belonged to the same color category or not. After briefly viewing the color arrays, participants indicated on which side of the visual field an oddball target stimulus was located. They found that participants performed better when oddball belonged to a different category than distractors compared to when it was from the same category, but only when targets appeared in the RVF, which the experimenters interpreted as a language-induced CP effect for color-based visual search. Unlike color, most visual stimuli don't belong to natural, continuously varying continuum, making it difficult to explore the effects of CP while simultaneously controlling for physical distances between stimuli. To solve this problem, in another study, Gilbert et al. (2008) generated different levels of morphed stimuli by combining images of two animal silhouettes, creating a continuously changing animal shapes. Like colors, they found lateralized CP effects during processing of familiar shapes.

Of course, faces also don't naturally vary on a continuum. To create an artificial spectrum of continuously changing stimuli, Rothstein et al. (2005) morphed faces of two familiar people. Their findings suggest that faces corresponding to different individual identities are better discriminated than

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different exemplars of faces within one identity. In contrast to color and shape (Gilbert et al., 2006; 2008), this *between-identity advantage* was found only in the RH. Interestingly, findings from face emotion categorization studies (Burt & Hausmann, 2019) suggest that faces from different categories (e.g., sad vs happy) should be better distinguished in the LH than RH potentially due to the language-induced CP. Moreover, some evidence suggests that face gender processing might be associated with the LH (Thorne, Hegarty, & Catmur, 2015). Taken together, these results suggest that processing of identity- and categorical-based changes in faces might rely on different mechanisms with different lateralization patterns—the RH for identity recognition and the LH for language-induced categorical perception.

Here, in three DVF search experiments, we examine the role of categorical (gender) and identity changes in lateralized processing of face stimuli.

In the first experiment, we focus on familiar face identity processing. We expect that overall participants will be better at distinguishing faces belonging to two different identities compared to the ones belonging to the same identity—*between-identity advantage*. However, in line with fMRI results in Rothstein et al. (2005), we predict that this result will be limited to the RH, previously shown to be crucial for face identity recognition.

In the second experiment, we explore how CP influences processing of unfamiliar gender faces. We predict to see overall improvement in performance when participants see faces of different gender compared to different faces of the same gender. However, unlike to identity processing, we expect to find LH lateralization for this effect—in accordance with prior literature showing LH lateralization for face gender recognition (Thorne, Hegarty, & Catmur, 2015).

In the third experiment, we combine gender and familiar identity dimensions so that faces can be distinguished based on both identities and gender. This experiment is exploratory in nature thus we don't provide a priori hypothesis. We might see a collaborative involvement of both hemispheres in processing between-identity and between-gender changes. Alternatively, one dimension (identity or gender) might be more salient than another, leading to dominant involvement of one hemisphere, specialized in processing of the dominant feature.

Methods

Participants

A total of 100 volunteers participated in three experiments run in parallel ($N_{Identity}$=36; $N_{Identity-Gender}$=31; N_{Gender}=33). Prior to the main task, participants in the identity and gender experiments took part in the staircase experiment (Kaernbach, 1991) to determine individual perceptual thresholds for familiar face identities and gender categories. Observers were naive to the underlying aims of the experiments and reported normal or corrected-to-normal vision. Participants were undergraduate students in the Psychology Department. Volunteers received course credit for their participation. Prior to participating, each observer provided informed consent according to the guidelines of the Department of Psychology and the Institutional Review Board of our organization.

Materials

For the staircase experiments, a continuum of 100 faces was generated using the Fantamorph sotware (Version 4; Abrosoft Co., Beijing, China). Fantamorph interpolates two original images to create morph continua of stimuli from two parent images. For familiar identity experiment, parent images were 100% Brad Pitt and 100% George Clooney pictures. 98 images were created by morphing these two faces by increments of 1% (See Figure 1A for the stimuli subset). We used the same strategy for generating gender (partens: a female and a male), and identity/gender morphs (parents: Charlize Theron and Brad Pitt). For the DVF search tasks, we chose four morphed faces (5%, 35%, 65%, 95%) out of those 100 based on participants' perceptual thresholds determined in the staircase experiment (Figure 1B). Stimuli were 2.5 cm in width and 3.8 cm in height, yielding visual angles of 3.8º and 5.7º, respectively when viewed from 38 cm distance. Stimuli were presented using the MATLAB package, Psychophysics Toolbox v. 3.0.10 (Brainard, 1997) on a Dell Precision T1650 (Intel Xeon E3 3.5 GHz) with 24-inch display, 1920 x 1200 resolution.

Procedure

In all three experiments, we used the divided visual field method (DVF) where observers performed a visual search task on arrays of faces split between the LVF and the RVF (modification of Gilbert et al., 2006). The search tasks required visual discrimination of faces by virtue of identity (Experiment 1), gender (Experiment 2), or both (Experiment 3). The staircase experiment was used to control for perceived distances between faces.

Staircase experiment Trials began with a central fixation cross (170 ms) followed by a mask (200 ms), and then a face array (200 ms). Participants had to report which identity/gender the face had (e.g., Bradd Pitt or a female) by pressing either 'J' or 'K' on a computer keyboard with their dominant hand. We used a 'weighted up-down staircase method' (for details see Kaernbach, 1991). To find the threshold where participants' perceptual discrimination rate was at 80%, in each correct trial, we increased the difficulty by 1 step, and decreased it by 4 steps after each incorrect response. The experiment ended after ten reversals.

Divided visual field experiments Trials began with a central fixation cross (1000 ms) followed by a stimulus display consisting of two arrays—each with three faces—one on the left and the other on the right side of the fixation cross. The distance between the two arrays was 8º. Five faces were identical (distractors), one was different (target). Target (oddball) was either of the same identity/gender as distractors or of a different one. On each trial, participants reported on which side of the fixation cross the target face was by pressing the left ('J') or the right ('K') keys on the keyboard. The visual search display remained visible until participant's response, maximum for 3000 ms (Figure 1C). Following response, fixation cross reappeared and the next trial began. There were 6 target-distractor pairs in each experiment, formed by using all pairwise combinations of the four faces (e.g., within-identity pairs: George 5%-George 35%, George 65%-George 95%; between-identity pairs: George 5%-George 65%, George 5%-George 95%, George 35%-George 65%, George 35%-George 95%. For between-identity trials, we only focused on the analysis of 1-step pairs (e.g., George 5%-George 35%) as it is only at this step size that both within- and between-identity pairs exist. Target-distractor pairs were formed similarly for the other two experiments, but stimuli were different (Figure 1B). Each pair served as a target and a distractor in different trials, thus there were 12 possible target-distractor permutations. Target could occupy any of the 6 positions in the 2 arrays, creating 72 possible stimulus permutations. The order of trials was randomized. Eye-tracking was used to control for gaze fixation.

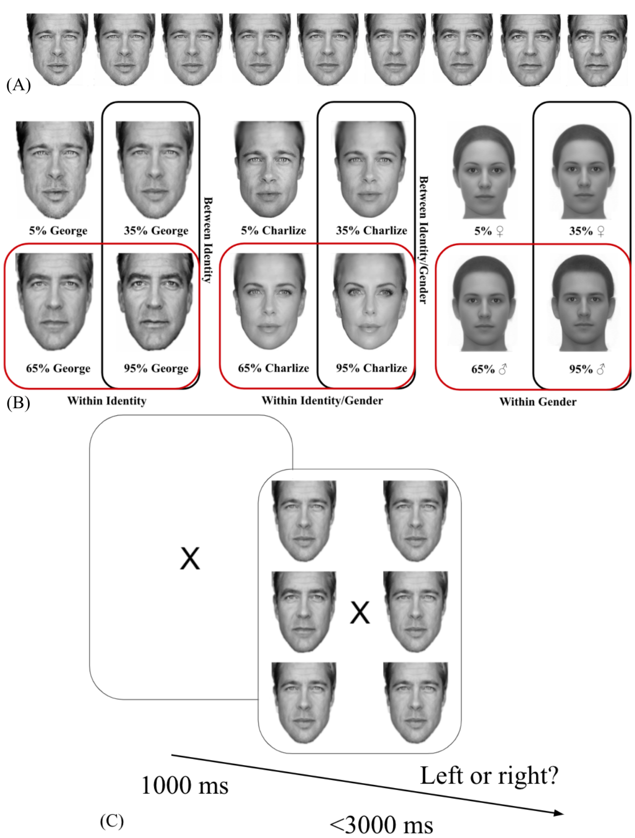

Figure 1: (A) A subset of graded continuum of faces used in the staircase experiment for establishing perceptual categorical boundaries among morphs of two parent stimuli, in this case Brad Pitt and George Clooney (B) For each DVF search experiment, four stimuli were chosen based on the perceptual boundaries established in the staircase experiment. (C) An example trial in the DVF search task

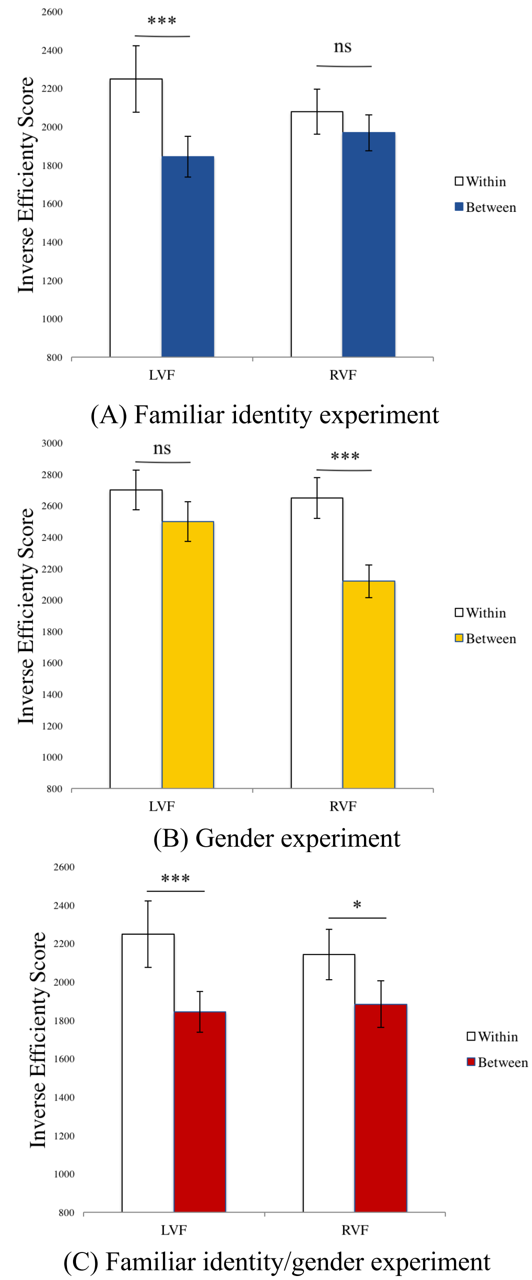

Figure 2: (A) Categorical perception facilitates identity discrimination only in the LVF. (B) For gender, CP affects perception only in the RVF. (C) CP effects exist in both hemifields for the stimuli varying on both, familiar identity and gender dimensions.

Results

Overview

Categorical perception influenced face identity and gender perception both as expressed in participants' response accuracy and reaction times. Interestingly, CP effect exhibited different lateralization pattern for face identity vs face gender processing.

Familiar identity task To assess participants' performance, we calculated inverse efficiency score (IES). IES (expressed in milliseconds) equals to the mean RT (for button press) divided by the proportion of correct responses, calculated separately for each condition and participant. Lower IES scores indicate better performance (Akhtar & Enns, 1989). IES offers a succinct description of behavior, allowing for easier interpretation of results. We analyzed IES scores using a 2 (visual field: left vs right) x 2 (distractor-target type: within vs between) repeated-measures ANOVA. Search performance was better for between- versus within-identity changes (lower IES for 65%-35% than 65%-95% target-distractor pairs) for targets with gender-matched distractors (main effect: F(1, 35 = 27.09, $p < .001$, $\eta_p^2 = .44$), but only for stimuli presented in the LVF (interaction RVF/LVF: F(1, 35) = 16.31, $p < .001$, $\eta_p^2 = .32$); LVF: t(35) = 5.56, $p < .001$, RVF: $t < 1$) (Figure 2A).

Gender task Here, we found a main effect of the distractor-target type on the IES scores, F(1, 32) = 38.02, $p < .001$, $\eta_p^2 = .40$, with better performance for the between-gender compared to the within-gender ones. There was no main effect of the visual field, F(1, 32) = 3.44, $p = .07$. The interaction between distractor-target type and hemifield was significant, F(1, 32) = 4.37, $p = .04$, $\eta_p^2 = .30$. The interaction was driven by significantly better performance for between-gender pairs compared to the within-gender pairs in the RVF, but not in the LVF, $p < .001$ and $p = .24$, respectively (Figure 2B).

Familiar identity/gender task Similar to the familiar identity task, we analyzed IES scores using a 2 (visual field: left vs right) x 2 (distractor-target type: within vs between) repeated-measures ANOVA. In contrast to the first experiment, between-identity advantage was found in both hemifields (main effect of target-distractor pair: F(1, 30) = 57.22, $p < .001$, $\eta_p^2 = .66$, neither interaction, nor the main effect of the visual field were significant, ps > .05) (Figure 2C).

Discussion

In all three experiments, people performed better when the target stimulus' identity/gender was different from distractors' identity/gender. However, lateralization of this effect changed as a function of the stimuli type. Specifically, familiar face identity processing was facilitated by CP only when the target stimulus was in the LVF. While the opposite was true for face gender processing—participants were faster and more accurate in the between-gender compared to the within-gender trials only when a target stimulus is presented in the RVF. Interestingly, for stimuli varying across both familiar identity and gender dimensions CP effects were present in both visual fields.

Categorical perception of faces

Categorical perception effects on visual perception are well-established in the literature. CP has been found to facilitate processing of diverse set of visual stimuli, such as color, shape, and motion (Gilbert et al., 2008; Holmes et al., 2009; Meteyard, Bahrami, & Vigliocco, 2007). These effects are often attributed to top-down linguistic modulation (Simanova et al., 2015). Some evidence that supports language-elicited CP shows the following: (1) CP effect (at least in simple visual stimuli, such as colors and shapes) is more strongly lateralized in the LH—known to be responsible for language-related processes (Holmes and Wolff, 2012)—compared to the RH (Mo et al., 2011); (2) CP is susceptible to verbal, but not non-verbal interference (Gilbert et al., 2006; 2008), and (3) CP doesn't influence pre-linguistic infants (Franklin et al., 2008). These studies have focused on visual perception of simple stimuli that do not exhibit strong lateralization biases.

What about more complex, right-lateralized visual processes, such as face perception? We found that face identity and gender perception improve when presented faces belong to different identities/categories, despite controlling for physical distance between stimuli. CP effect—traditionally thought to be lateralized to the LH—influenced face processing which exhibits strong RH bias. These results raise the question of whether the lateralization patterns underlying CP of faces are like those seen in color and shape experiments.

Lateralization patterns in face gender and identity processing

Even though face processing is one of the most well-established lateralized processes, most of the findings supporting the strong RH bias for faces stem from the studies of face identity processing (Kanwisher, McDermott, and Chun, 1997; Rotshtein et al., 2005). However, different body of research shows that the LH might be responsible for certain dimensions of face perception (Levine, Banich, & Koch-Weser, 1988; Sergent & Bindra, 1981). For example, Rossion et al. (2000) found that the right middle fusiform face gyrus was activated when participants had to match whole faces rather than the parts of the face, whereas this lateralization pattern was reversed when they were using part-based matching strategy. The LH is also involved in the categorization of emotional facial expressions potentially due to biases related to language (Burt & Hausmann, 2019). Another study found that *androcentrism*—the tendency of designating people to be men or male by default—is supported more readily in the left compared to the right hemisphere, again suggesting the role of language-elicited CP in gender processing (Thorne, Hegarty, & Catmur, 2015). In this study, we aimed to dissociate different aspects of face perception relying on opposite lateralized processes.

We used the DVF search paradigm (Gilbert et al., 2006) to explore underlying lateralized processes during categorical perception of faces. In three experiments, we compared people's performance on the DVF search tasks for face stimuli that differed by familiar identity, gender, or both. Interestingly, lateralization patterns differed across the three experiments.

In the familiar identity task, the processing of between-identity changes was found to be easier compared to the within-identity changes only in the LVF, suggesting that this beneficial effect of between-identity changes might be related to general face processing networks in the right lateralized fusiform face area (FFA) rather than elicited by linguistic CP effect. Prior work showed that FFA is sensitive to the changes in faces at individual, identity level (Axelrod & Yovel, 2015; Gauthier et al., 2000). Our results are also consistent with literature showing that between-identity processing benefit is lateralized to the right hemisphere (Gauthier et al., 2000; Kanwisher & Yovel, 2006; Rotshtein et al., 2005; Schiltz et al., 2010).

In contrast to identity processing, the lateralization pattern was reversed for the categorical perception of gender. After 'removing' familiar identity dimension from the face stimuli, CP effect was only seen when the target face was in the RVF (LH). This LH lateralization pattern suggests that CP processing of gender might be dependent on general, language-related categorical processes seen previously found in color and shape domains (Gilbert et al., 2006; 2008).

Interestingly, when we combined face identity and gender dimensions, hemifield advantages disappeared—participants performed better in between-category/identity than within-category/identity trials in both hemifields. These results might reflect the cooperative engagement of both hemispheres responsible for different dimensions of face stimuli—LH for gender and RH for identity processing. Further studies using linguistic interference paradigms will test whether separate—language- and identity-elicited—CPs are indeed responsible for lateralization differences during processing of face gender and identity.

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