University of Nevada, Reno

A Divided Visual Field Approach to the Categorical Perception of Faces

A thesis submitted in partial fulfillment of the
requirements for the degree of Master of Science in
Neuroscience

by

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May, 2019

THE GRADUATE SCHOOL

We recommend that the thesis
prepared under our supervision by

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entitled

A Divided Visual Field Approach to the Categorical Perception of Faces

be accepted in partial fulfillment of the
requirements for the degree of

MASTER OF SCIENCE

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May, 2019

Abstract

The perception of boundaries between stimuli that exist along a graded continuum of physical properties is referred to as categorical perception. Categorical perception is often interpreted as evidence that language influences perception. Consistent with this, divided field studies of color and shape perception showed a relationship between categorical perception and cerebral laterality for language. Unlike color and shape perception, face recognition is associated with right-lateralized circuits in visual cortex and beyond. We hypothesized that the well-known left visual field (LVF) advantage for face recognition would show modulation by categorical versus non-categorical face perception. In two experiments, we used a divided field method in which observers performed a visual search task on arrays of faces split between the LVF and the right visual field (RVF). The search tasks required visual discrimination of faces by virtue of either identity or gender. Our results confirmed the existence of categorical face perception in both types of task. Crucially, however, we found greater categorical perception of identity for LVF faces and the opposite (RVF) for categorical perception of face gender. Our findings show that categorical effects on face recognition depend on opponent cerebral laterality for language and the visual processing of faces.

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Introduction

Is language just a faculty humans use to communicate about our feelings and experiences with greater success than other animals, or does it also augment our cognition and perception? Many have discussed the power of language on cognition (Whorf, 1956; Dennett, 1994), and there is ongoing debate about the "Whorfian" theory that language influences our perception. A growing number of empirical studies show that language can affect non-verbal processes. For the reviews about the "language and thought" debates, see Boroditsky, 2003; Casasanto, 2008; Boroditsky, 2010. Prior studies have shown that domains ranging from color perception (Winawer et al., 2007), motion perception (Meteyard et al., 2007), and categorization (Lupyan et al., 2007) are affected by language. Even though many sensory stimuli vary continuously along a spectrum, humans tend to divide these spectra into discrete categories. Categorical perception refers to findings that we represent a graded continuum of stimulus change (e.g. wavelength, facial expression) as having category boundaries (e.g., colors, emotions) and differences that cross category boundaries are more easily discriminable than differences within category boundaries, when the degree of physical difference is held constant. Findings of categorical perception for basic stimulus properties, such as color, have been taken as evidence that language influences perception (Winawer et al., 2007). Despite extensive work on the relationship between language and perception, much of the work studying this area has focused on simple visual stimuli, such as color and shapes. Unlike color and shape perception, face recognition is associated with right-lateralized circuits in visual cortex and beyond (Kanwisher, 1997), while language and categorical perception are more strongly lateralized to the left hemisphere (LH) (Holmes and Wolff, 2012). Here, we investigate the role of the categorical perception in the processing of complex, right-lateralized stimuli, like faces.

Recent behavioral studies of color and shape perception showed a relationship between categorical perception and cerebral laterality. For right-handed individuals, language processing is more strongly associated with the left hemisphere (LH) compared to the right hemisphere (RH) (Wada, Clarke, & Hamm, 1975). LH preference for language-related tasks has been demonstrated using different experimental methods, including functional brain imaging (fMRI) (Dehaene-Lambertz et al., 2002) and behavioral methods, such as divided visual field

(DVF) tasks (Ossowski and Behrmann, 2014). Given that language is lateralized in the brain, and the crossing of projections in the visual system, the Whorfian effects should be stronger for the stimuli presented in the right visual field (RVF) compared to the left visual field (LVF). Gilbert et al. tested this hypothesis using a visual search task with colored squares and showed that reaction times (RTs) were faster when the target belonged to a different lexical category than the distractors (e.g., green among blues) compared to when the target was from the same lexical category as distractors (e.g., two different hues of blue) (2007). They also showed that this effect was seen only in RVF. Gilbert et al. showed the same effect for animal silhouettes (2007). The lateralized Whorf experiments conducted to date have focused on simple visual stimuli, such as colors and silhouettes. If the effects of language on perception are generalizable, we should see categorization effects on more complex stimuli, as well. In this study, using a paradigm modified from Gilbert et al. (2006, 2007), we explore the relationship between language and human perception in the context of brain lateralization using faces as an example of complex visual stimuli.

Face processing is one of the most well-studied visual processes in the context of brain lateralization. We know that an asymmetry in the brain exists for faces from studies of prosopagnosia patients in which RH damage is enough to elicit problems in face processing (Sergent and Signoret, 1992). This relationship has been also shown using fMRI (Kanwisher, 1997) and behavioral methods (Hausmann, 1999). However, the experimental results of face processing in the context of lateralization are not straightforward – despite stronger involvement of RH, LH is also involved in this process (Puce et al., 1996). Rossion et al. (2000) showed that face processing might be decomposed into two distinct processes: whole-based process and part-based process. They found that right middle fusiform face gyrus is activated when participants have to match whole faces rather than the parts of the face, whereas the pattern of activity was reversed in the left homologous region when they judged faces by parts. The study by Rossion et al. shows the importance of decomposing complex stimuli for identifying the roles different hemispheres play in the processing. Roberson et al. also showed that LH is involved in facial expression recognition (2010). Thus, both hemispheres may be involved in face processing, although they may each play different roles.

The LH role in face processing might be due to its dominance in language-related tasks, meaning that different facial categories (gender, identity) are a linguistic phenomenon (Roberson et al., 2010). In this case, faces that are of different identity/gender should be better discriminated compared to the faces that are of the same identity/gender, when the physical difference is the same and this effect should be stronger in the RVF. These results would identify the different roles of hemispheres in face processing. On the other hand, face identity processing is strongly lateralized to the RH (Rotshtein et al., 2005) and this lateralization might be resistant to the language dominance in the LH.

Although both, categorical perception and face identity and gender processing have been extensively studied, their possible relationship has not been assessed. With this study, we aim to fill this gap in the literature and assess the different role of hemispheres in face identity and gender processing in the context of categorical perception. Specifically, we are interested whether categorical perception effects can be generalized to face identity and face gender processing and if yes, whether these effects are lateralized.

Methods

In two experiments, we used a divided field method in which 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 either identity or gender. Additionally, we used an adaptive staircase method to test each participant's individual perceptual threshold for face identity and gender categories to make sure that both, physical and perceptual distances were controlled. Staircase experiment begins with easy trials and the difficulty is increased trial after trial. If the observer makes a mistake, the staircase 'reverses' and the difficulty decreases, finally, calculating each participant's perceptual threshold for the stimuli categories.

Participants

A total of 72 volunteers participated in 2 experiments, run in parallel: Experiment 1 (28 in total, 18 females, mean age = 21.55): an adaptive staircase experiment followed by a main divided visual search task which was a partial replication of Gilbert et al. (2006) using morphed faces of famous people; experiment 2 (44 in total, 30 females, mean age = 22): the same paradigm with morphed faces of unfamiliar male and female faces. All participants participated in the staircase experiment prior to the main task. This experiment was designed to measure their perceptual thresholds for different categories. All observers were naïve to the underlying aims of the experiments and reported normal or corrected-to-normal vision. All participants were graduate and undergraduate students at the University of Nevada, Reno. Undergraduate volunteers were given course credit for participation. The experimental protocol adhered to the Declaration of Helsinki, and prior to participating, each observer provided informed consent according to the guidelines of the Department of Psychology and the Institutional Review Board of the University of Nevada, Reno.

Materials

For the staircase experiments, face continuum with 100 faces was created using the software FantaMorph (http://www.fantamorph.com/). For the first experiment, the continuum was ranging from 0% George Clooney to 100% George Clooney. Parent faces consisted of 1 Brad Pitt image and 1 George Clooney image. For the second experiment, the continuum was ranging from 0% female to 100% female. Parent faces consisted of 1 female and 1 male image (See Figure 1a).

In order to control for perceptual features, for the divided visual search task, we chose the four morphed images out of the 100 – 5%, 35%, 65%, and 95% Brad Pitt and George Clooney (male and female) (See Figure 2a) morphs - according to the participants' sensitivity to face morphs in the staircase experiment. Stimuli were 2.5 cm in width and 3.8 cm in height, yielding visual angles of 3.8º and 5.7º, respectively when participants viewed stimuli from 38 cm. Stimuli were presented on a Dell Precision T1650 (Intel Xeon E3 3.5 GHz), with 24-inch display, 1920 x 1200 resolution. The stimuli were presented with the Psychophysics Toolbox v. 3.0.10 (Brainard, 1997) for MATLAB (Mathworks Inc., Natick, MA) software package.

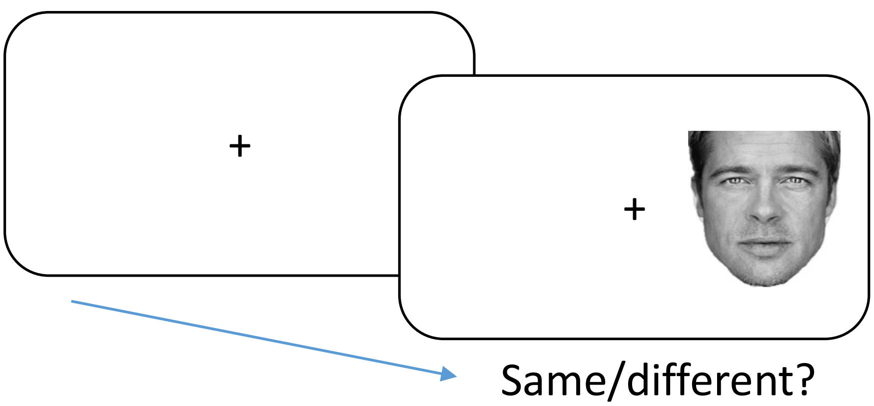
Procedure

Staircase Experiment

Participants were seated directly in front of the display with their chins seated on a chin-rest and viewed the stimuli from 38cm. As shown in Fig 1b, trials began with a central fixation cross (170 ms) followed by a peripherally presented face (200 ms) - presented 4º on the left or on the right side of the fixation cross - which was replaced with a mask (200 ms). Participants indicated whether the face was Brad Pitt or George Clooney (male or female) by pressing one of two labeled keys ("F" and "J", respectively) with their dominant hand. Morphed faces were equally likely to appear on the left or the right side. Here, we used a 'weighted up-down staircase method' (Kaernbach, 1991). To find the threshold where participants' perceptual discrimination rate was at 80%, we were increasing the difficulty by 1 step after each correct response and decreasing it by 4 steps after each incorrect response. A staircase stopped after ten reversals. One decreasing and one increasing staircase were measured for each face and each hemifield – in total four staircases. The staircases were measured in random order.

a

b



c

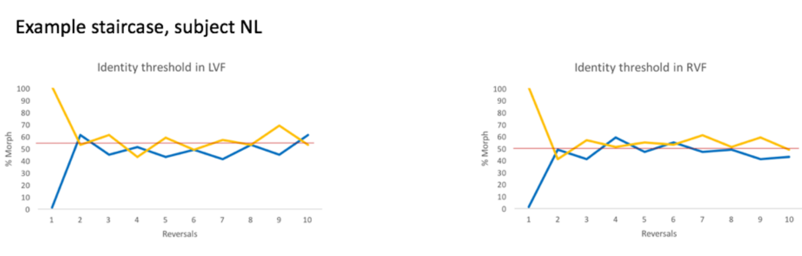


Figure 1. Perceptual judgments on the continuum was stable among participants and between two visual fields. (a) Face continuum used for the threshold experiment. (b) Experiment paradigm. (c) Staircase results show that participant NL draw the boundary between Brad and George when the face was ~53% morphed.

Divided Visual Search Experiment

In the divided visual search task, participants were seated directly in front of the display with their chins seated on a chin-rest and viewed the stimuli from 38cm. As shown in Fig 1b, 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 side and one on the right side of the fixation cross. The distance between the two arrays was 8º. Five of the six faces were identical (the distractors) and the sixth face was different (the target). The target was either of the same identity (e.g., Brad Pitt among different Brad Pitt faces) or of a different identity (e.g., George Clooney among Brad Pitt distractors).

Participants were asked to identify the side of the screen containing the target as quickly as possible. Responses were made by pressing one of two horizontally aligned keys on the keyboard, using either the left ("J" key) or right ("K" key) with their dominant hand for the Brad Pitt and George Clooney experiment. To account for the differences of dominant vs non-dominant hand, for the following two experiments (male vs female, Charlize Theron (female) vs Brad Pitt (male) we used keys "J" and "K" that could be pressed with one hand. The visual search display remained visible until the participant responded, for 3000 ms maximum. After that, the faces were replaced with a mask (200 ms). Following the response, the fixation cross reappeared and the next trial began.

There were 6 target-distractor pairs, formed by using all pairwise combinations of the four faces (e.g., Brad1Brad2, George1George2 (the two within-category pairs), Brad1George1, Brad1George2, George2Brad1, George2Brad2 (the four between-categories pairs)). Each pair served as a target and a distractor in different trials, thus there were 12 possible target-distractor configurations. The target could occupy any of the 6 positions creating 72 possible stimulus configurations. Each participant completed six 72-trial blocks. The order of trials was randomized. 7% of all trials were excluded, 67% of which were because of erroneous responses. There were no significant differences in RTs based on which stimuli in each pair served as a target. Eye-tracking was used to control the fixation. The trials where participants moved their eyes from the fixation were excluded.

a

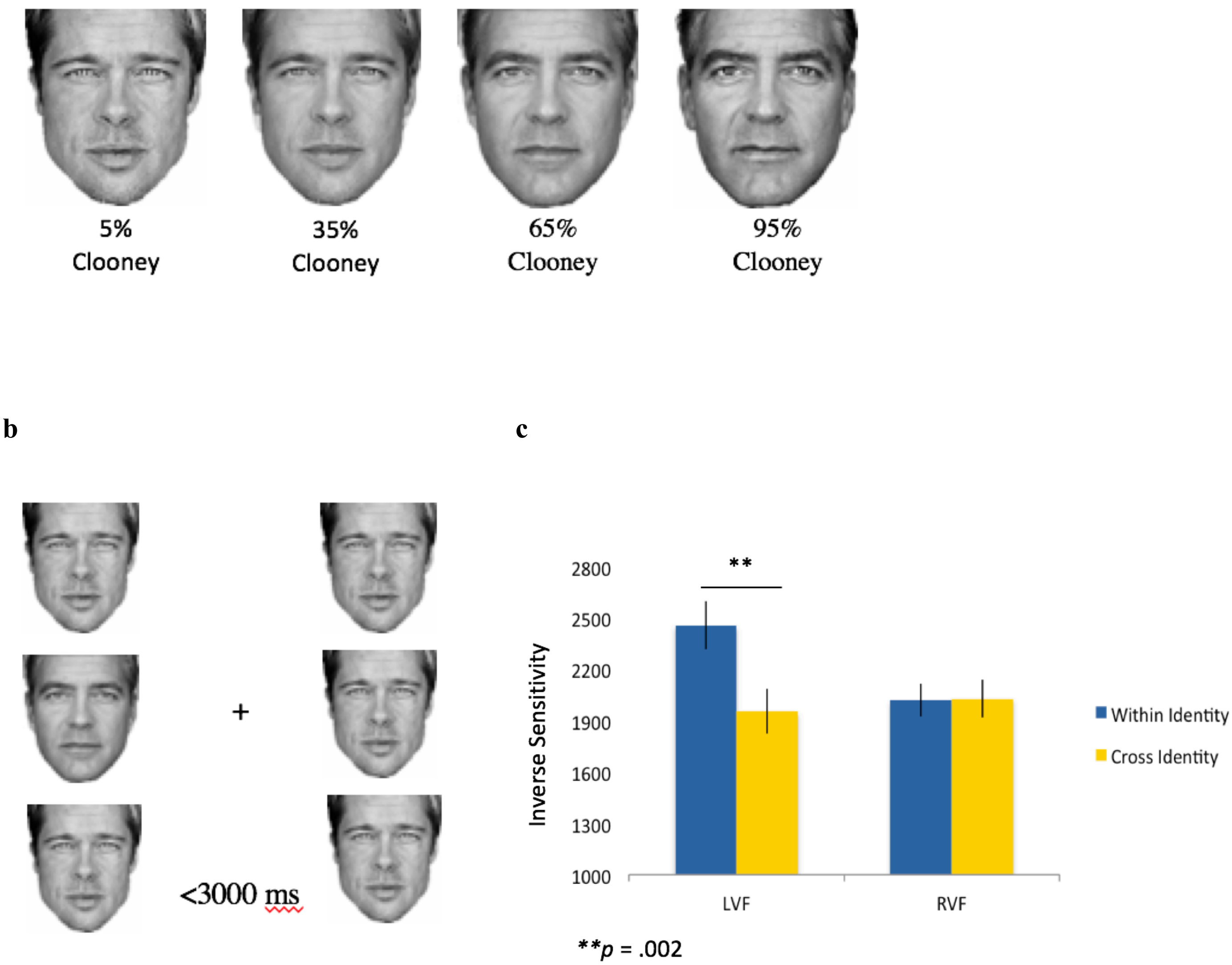


Figure 2. Categorical perception influences face identity processing in LVF. (a) Four morphed faces used for the experiment. (b) Experiment paradigm: in each trial there always was one different face either of the same or different identity and participants had to detect on which side (left or right) this different face appeared. (c) Participants were better at finding different face when the face was of different identity. Y axis shows combined

reaction time (RT) and accuracy measurements (Acc) - (RT/Acc). The effect of identity change was only significant in LVF.

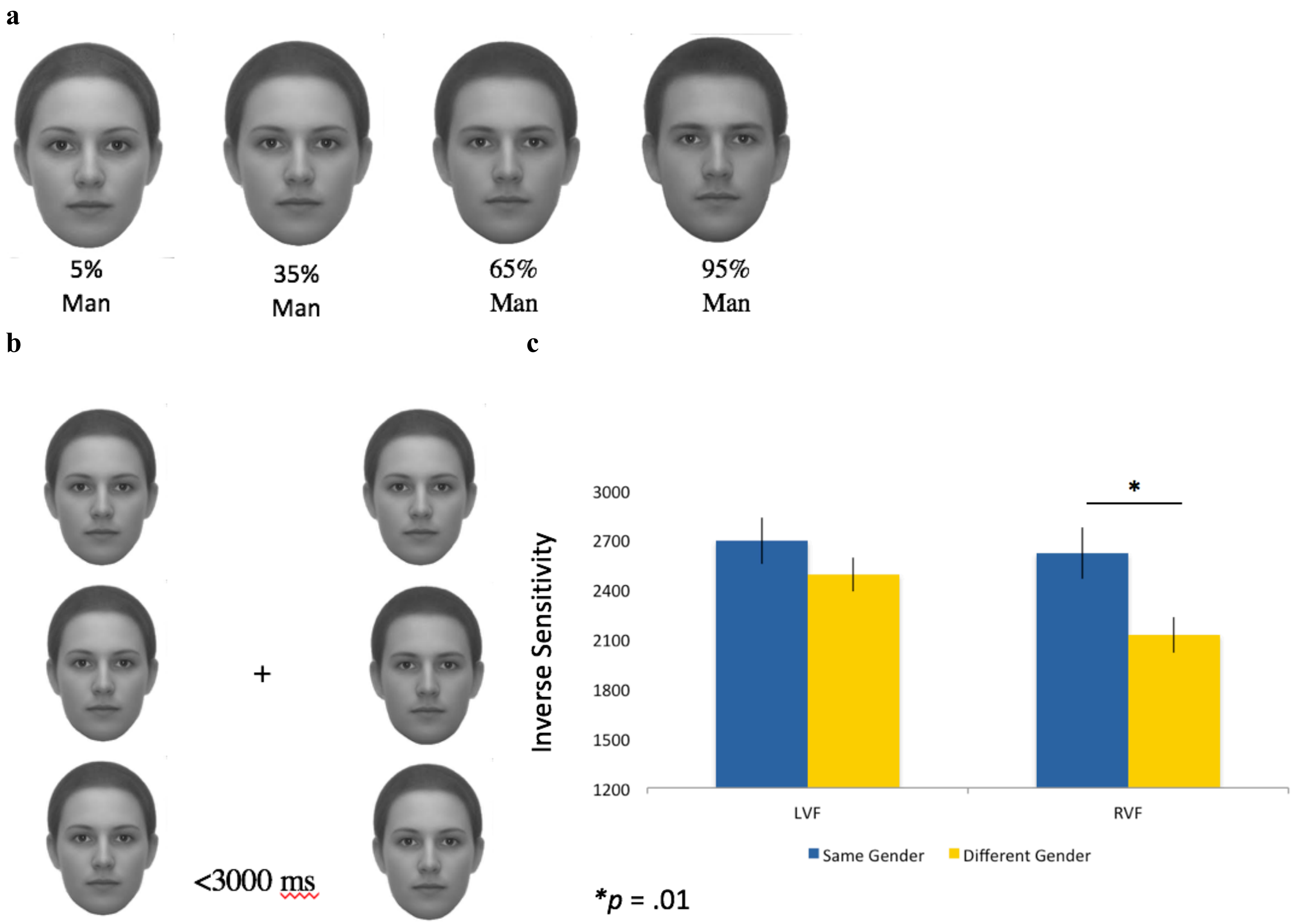


Figure 3. Categorical perception influences face gender processing in RVF. (a) Four morphed faces used for the experiment. (b) Experiment paradigm: in each trial there always was one different face either of the same or different gender and participants had to detect on which side (left or right) this different face appeared. (c) Participants were better at finding different face when the face was of different identity. Y axis shows combined reaction time (RT) and accuracy measurements (Acc) - (RT/Acc). The effect of gender change was only significant in RVF.

Results

We designed an adaptive staircase experiment to measure perceptual thresholds for the stimuli for each participant. The divided field visual search tasks were used to test whether categorical perception affected performance and whether this effect was lateralized. We performed analyses of response times (RTs) on correct responses in the visual search task, accuracies, and inverse efficiency scores (IES) that are combined RT and accuracy scores (Bruyer and Brysbaert, 2011). Abnormally short RTs (less than 200 ms) and outliers (defined as RTs more than two standard deviations from the individual mean of each participant), were excluded from analysis (3.8% of the RTs).

Adaptive Staircase

The adaptive staircase was used to control for perceptual features of the morphed faces by measuring each participant's sensitivity to different levels of morphed faces in both hemifields. The aim of this experiment was to find the levels of morphs that could be used for the visual search task. As shown in figure 6, the average threshold for Brad Pitt was 56% and for George Clooney - 60%. According to these results, four morphed faces were chosen for the visual search task: 5%, 35%, 65%, and 95% morphs. The step sizes between images were equal to control for physical differences. We used this experiment to make sure that the morphed faces we were using to represent within and between identity categories were in reality perceived as those categories by subjects (See Figure 2c).

Visual Search Task

Identity Task

Inverse sensitivities (IS) were analyzed using a 2 (visual field: left vs. right) x 2 (pair type: within vs. between) ANOVA. There was a significant main effect of pair type on ISs, $F(1, 17) = 11.78$, $p = .003$, $\eta_p^2 = .41$, meaning that participant's accuracies were higher and reaction times (RTs) were lower in between-identity trials compared to within-identity trials. There was no main effect of the visual field, $F(1, 17) = 1.54$, $p = .23$, $\eta_p^2 = .08$. But there was a significant interaction between the visual field and pair type, $F(1, 17) = 7.25$, $p = .02$, $\eta_p^2 = .30$. Follow up t-tests were used to examine the simple effects of condition on accuracies separately for each hemifield. For LVF, performance for between-category pairs was significantly better than for within-category pairs, $t(17) = 6.85$, $p = .01$, $\eta_p^2 = .17$. However, in RVF performance for between-category pairs did not differ from the within-category pairs, $t(17) = .004$, $p = .95$, $\eta_p^2 = .00$.

Gender Task

ISs were analyzed using a 2 (visual field: left vs. right) x 2 (pair type: within vs. between) ANOVA. There was a main effect of pair type on ISs, $F(1, 32) = 38.02$, $p < .001$ with ISs to between-category pairs being smaller compared to within-category pairs. There was not a main effect of hemifield, $F(1, 32) = 3.442$, $p = .07$. There was a significant interaction between the pair type and hemifield for ISs, $F(1, 32) = 4.37$, $p = .04$ (See Figure 3c).

Our results show that categorical perception affects face identity and face gender processing and this effect is lateralized. Interestingly, the lateralization patterns are different for face identity and face gender. The categorical effect is significant only in the LVF for face identity processing while it's significant only in the RVF for face gender processing.

Discussion

Categorical Perception of Face Identity and Gender

Different studies have shown that categorical perception can affect perception of simple visual stimuli, such as color and shape (Winawer et al., 2010; Gilbert et al., 2007). In this study, we first addressed the question whether this effect could be generalized to the complex stimuli, such as, face identity and face gender processing? Our results suggest that categorical perception effect can be seen for both, face identity and face gender processing.

Lateralized Categorical Perception of Face Identity

Studies of categorical perception of color and shapes have shown that this effect is lateralized and it is the strongest in the right visual field (Gilbert et al., 2006, 2007). This is consistent with general language lateralization to the left hemisphere. Here, we were interested to see whether categorical perception effects were always lateralized to the LH/RVF. In the first task, we used face identity stimuli. As face identity is very strongly lateralized to the RH (Rotsthein et al., 2004), we were interested whether we would see the opposite lateralization for categorical perception compared to the previous studies with color and shape. We found that this effect, indeed, was the strongest in the LVF – consistent with face, and specifically identity judgments being lateralized to the RH. These results suggest that contrary to previous findings, categorical perception might be happening not only in the LH but also in RH. Or for face identities, linguistic categorical perception might not be the reason driving this categorical effect.

Lateralized Categorical Perception of Face Gender

Next, we were interested whether categorical perception effects were always stronger in LVF for face stimuli. As identity processing is strongly lateralized to the RH, we decided to remove that layer from our stimuli and to go to superordinate category, such as gender. Interestingly, in the gender experiment, categorical perception effect was opposite, it was stronger in the RVF – consistent with the findings of color and shape studies. These findings show that categorical effects on face recognition might depend on opponent cerebral laterality for language and the visual processing of faces.

These results support previous findings showing that identity processing is strongly lateralized to the RH (Rotshtein et al., 2004). Interestingly, when we removed the identity layer and participants are processing face gender, the left-lateralized language-related processing influenced the task stronger, moving the categorized effect to the RVF. Here, we also show LH's role in face processing that might be the result of the categorization being more strongly lateralized to the LH.

In addition to finding differences in categorical perception effects in two hemifields, our results once more showed that linguistic categories influence, more specifically improve performance in visual perception tasks.

In summary, there is a strong categorical perception effect on face identity and face gender processing. In addition, both left and right hemispheres are able to process face identity and face gender, but the influence of categories is stronger in RVF for face identity processing, while it is stronger in LVF for face gender processing indicating for the possible strong role of language in this task.

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