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The “Fat Face” illusion: A robust adaptation for processing pairs of faces

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Abstract

Converging evidence has demonstrated our remarkable capacities to process individual faces. However, in real-life contexts, we rarely see faces in isolation. It is largely unknown how our visual system processes a multitude of faces. The current study explored this question by using the “Fat Face” illusion: when two identical faces are vertically aligned, the bottom face appears bigger. In Experiment 1, we tested the robustness of this illusion by using faces varied by gender and race, by recruiting participants from different countries (Canadian, Chinese, and French), and by implementing different task requirements. We found that the illusion was stable and immune to variations in face gender or face race, perceptual familiarity, and task requirements. Experiment 2 further indicated that binocular vision was essential for this visual illusion. When participants performed the task with one eye covered, the previously robust illusion completely disappeared. Together, these findings revealed a visual adaptation to multiple faces in the environment: The face, which is higher in the picture plane, is perceived more distant from the viewer and appears smaller in size. And the lower face is perceived closer to the viewer and appears larger. More broadly, overestimating the size of the bottom face might act as a fundamental mechanism for social interactions, ensuring the deployment of attention to those closest to self.

Keywords: “Fat Face” illusion, face processing, depth perception, binocular vision

Highlights

- The “Fat Face” illusion indexed a special perceptual mechanism for multiple faces
- The illusion was not affected by face categories, experiences, or task requirements
- The visual system augments the perceived size of the face at the bottom
- The illusion relied on binocular vision
- The illusion indexes a visual adaptation to the environment

From supermarkets to classrooms, crowds are a daily reality. In these busy scenarios, each face provides crucial social information about an individual's social category and identity. Given their high social value, faces hold a special place in the human visual system, which is reflected through many face-specific cognitive adaptations. We possess highly specialized and efficient perceptual capacities for faces (e.g., holistic face processing, Diamond & Carey, 1986; Michel et al., 2006; Rossion & Retter, 2020; Yin, 1969; Young, Hellawell, & Hay, 1987), and is supported by specialized neural circuitry (e.g., Fusiform Face Area, Kanwisher et al., 1997). Moreover, a brief exposure to faces instantaneously activates a wide range of social information (Locke et al., 2005; Macrae & Bodenhausen, 2000; Willis & Todorov, 2006). These adaptations render the visual system highly efficient in recognizing faces and extracting rich information from individual faces.

In typical social settings, faces are rarely presented in isolation, and we often see multiple faces in our environment. Although processing information from many faces may seem challenging, our visual system has developed sophisticated mechanisms to summarize facial information (e.g., emotional expression, race, and gender) among multiple faces (Haberman & Whitney, 2007, 2009; Haberman et al., 2009; Bai et al., 2015). These cognitive capacities enrich perceptual and social experiences and provide access to valuable information about social and physical relations in a group, such as their relative size, relative distance, or dominance relations, unavailable otherwise from individual faces. For example, the simultaneous body movements of a musical quartet revealed the quartet leader when observed as a unit, but not when analyzed separately (Chang et al., 2017). Interpersonal distance, relative body posture, and position during communication reliably disclosed individuals' social status (e.g., Hall et al., 2005; Mehrabian, 1969). Despite the social and perceptual information embedded in groups of individuals, how our

visual system represents such relational information remains largely unknown. To probe this question, the current study investigated a visual adaptation for processing two faces presented in a vertical layout.

Prior studies have reported a phenomenon revealing how our visual system processes pairs of faces. Sun and colleagues (2012, 2013) first reported how the vertical layout of two faces biased our perception of face size. As shown in Figure 1, when two identical faces were vertically displayed, the bottom face appeared bigger than the top face. This illusion, referred to as the “Fat Face” illusion, was specific to upright human faces. The illusion disappeared with inverted faces, objects with a canonical orientation, similar in shape and size to a human face (e.g., clocks), or scrambled faces that disrupted the normal face template (Sun et al., 2012, 2013). These early studies revealed that the illusion is face-specific, raising the question of whether the illusion is connected with experience with faces. More recent primate studies suggested that the “Fat Face” illusion was specific to humans because chimpanzees were not susceptible to this illusion (Tomonaga, 2015). Its specificity suggests that the illusion might be an adaptive outcome of rich and frequent social interactions in human societies. In summary, the “Fat Face” illusion captures a special perceptual representation of pairs of faces in our visual system and offers a unique opportunity to study how humans visually represent multiple faces. However, the nature and the mechanism of this illusion remain largely unknown. To this end, the current study explored how our visual system represents multiple faces via this illusory perception of face size.

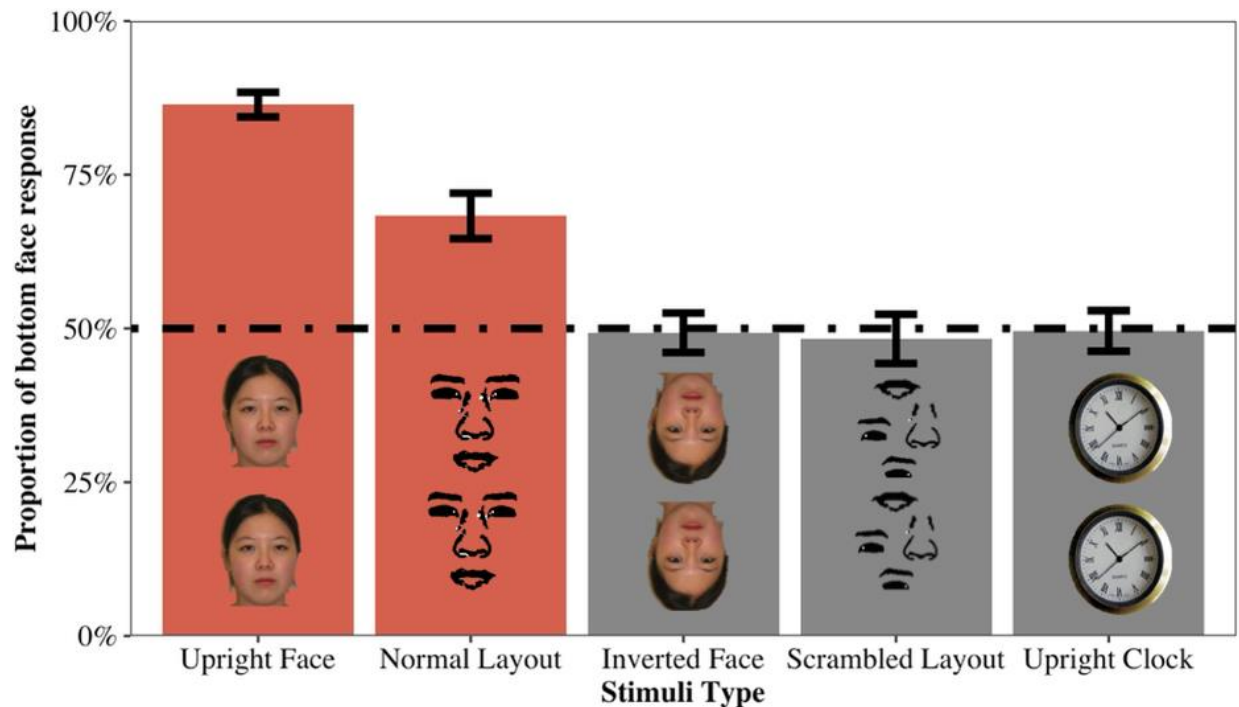


Figure 1. The “Fat Face” illusion, where participants systematically perceived the bottom face of the two identical faces as bigger. The proportion of bottom choices for five types of stimuli: Upright Faces, Internal Facial Features, Inverted Faces, Scrambled Facial Features, and Clocks (reported from Sun et al., 2012, 2013). The dashed line represents the 50% expected rate of bottom face response. Error bars indicate one standard error from the mean.

To investigate the nature of the “Fat Face” illusion, we designed two experiments. Experiment 1 examined whether the illusion was modulated by experience with face categories (e.g., race and gender). Decades of research on individual faces has revealed the dual nature of adults’ highly optimized face processing abilities. Prior to any experience, humans already have a general predisposition for faces: fetuses and newborns are already sensitive to face-like visual patterns (Goren et al., 1975; Johnson et al., 1991; Reid et al., 2017; Valenza et al., 1996). However, some face processing abilities are shaped by the faces that we encounter. Experience with faces in the first months of life tunes face processing system to the most representative

exemplars in the environment, such as primary caregiver, own-race faces, and conspecific faces (e.g., Anzures et al., 2013; Kelly et al., 2005; Kelly et al., 2007; Pascalis et al., 2002; Quinn et al., 2002). The specialized processing of highly familiar faces remains a robust phenomenon in adulthood. For example, face processing is impaired by uncommon face orientations, such as inverted faces (for a review of the inversion-effect see Rossion & Gauthier, 2002). Adults' face processing abilities continue to be disrupted when unfamiliar other-race faces are tested (for a review of the other-race effect see Meissner & Brigham, 2001). Inspired by these studies on processing a single face, we first examined if the "Fat Face" illusion develops as a result of face experience or whether it is an adaptive function, independent of face experience. This question has not been addressed, as prior studies only examined the illusion with faces of the same race as participants' (Sun et al., 2012, 2013).

To this end, Experiment 1a investigated the illusion as a function of two major facial categories: race (Asian and Caucasian) and gender (female and male). If the "Fat Face" illusion emerges as a result of face experience, we expected the size of the illusion to be modulated by face gender or face race. Face gender and race are two major face categories that define the faces that we see (e.g., Rennels & Davis, 2008). From infancy to adulthood, face gender and ethnicity information impact face processing at multiple levels, ranging from attention (e.g., Liu et al., 2015a; Liu et al., 2015b; Quinn et al., 2002), face recognition (e.g., Meissner & Brigham, 2001; Tanaka et al., 2004), and social cognition (e.g., Kinzler & Dautel, 2012; Kinzler & Spelke, 2011; Shutts, 2015). To probe the potential impact of face experience on the illusion, we conducted the experiment in Canada, China, and France. French participants were Caucasian and had mostly been exposed to Caucasian faces. By contrast, participants in China were Asian and had mostly been exposed to Asian faces. The Canadian sample included participants from diverse ethnic

backgrounds. The Canadian participants were previously exposed to both Caucasian and Asian faces. The contrasting face race experience among participants from the three countries was essential to examine whether any face race-related effect was due to face ethnicity (e.g., Asian vs. Caucasian faces), or due to participants' experience with faces (e.g., own- vs. other-race). Experiment 1b explored the effect of face categories on the illusion in the absence of idiosyncratic features of faces, such as hairstyle or face contour, previously shown to modulate the "Fat Face" illusion (Sun et al., 2013; Rawal and Tseng, 2020). Previous research showed that the geometric shape of objects (top wide bottom narrow) can lead to an overestimation of the size of the bottom object, so this manipulation was crucial to confirm the face-specificity of the "Fat Face" illusion. Furthermore, Experiment 1c ensured that the illusion does not capture a mere response bias, by instructing participants to select the face that appeared smaller to them. If the illusion captures a perceptual phenomenon, participants should switch their responses in favor of the top face.

Experiment 2 explored the underlying mechanism of this size illusion by focusing its dependency on binocular vision. The face-specificity of this illusion implies that the illusion may originate in how we experience faces at different locations in the environment along a vertical axis. Typically, individuals higher in the picture plane are usually more distant from the viewer, and appear smaller in size, while individuals lower in the picture plane are closer to the viewer and appear larger (Epstein, 1966; Roelofs & Zeeman, 1957). In other words, the vertical layout signifies a subtle difference in the proximity of the two faces, where the lower face is closer to the viewer than the upper face. In real-world scenarios, we rely on both eyes, and rarely use only one eye, to perceive how close a person is to us. Binocular vision serves as the dominant way to obtain distance information of people, thereby being more sensitive to a subtle difference in

depth than monocular vision. This prediction is in line with recent findings that adults had a much higher depth discrimination threshold with monocular vision compared with binocular vision when they were tested in a natural environment (Allison et al., 2009). To this end, Experiment 2 examined the prediction by comparing the size of the “Fat Face” illusion between binocular and monocular conditions. We predicted that monocular vision would eliminate this illusion.

To support Open Science, all face images, experiment data, and analysis scripts are available at our OSF (Open Science Foundation) repository

(https://osf.io/wxf7v/?view_only=5c990affe1fd4ac6a64a04abec2ab099).

1. Experiment 1a

1.1. Methods

Participants. A total number of 91 adults were recruited from three countries: Canada ($N = 31$, 25 females, $M_{\text{age}} = 18.20$ years, $SD = 1.42$ years), China ($N = 30$, 15 females, $M_{\text{age}} = 22.53$ years, $SD = 1.96$ years), and France ($N = 30$, 17 males, 12 females, & 1 not disclosed, $M_{\text{age}} = 24.90$ years, $SD = 5.03$ years). The Canadian participants were from diverse ethnic backgrounds: 11 Caucasians, 15 Asians, 4 Arabic, and 1 African. All Chinese and French participants were ethnically homogeneous: Chinese participants were Asian, and French participants were Caucasian. Canadian participants were university students who participated in the study online and received course credit for their participation. Chinese participants were university students who performed the experiment in a lab and were remunerated with course credit for their participation. French participants were recruited online on the academic participant pool Prolific (www.prolific.ac) and were compensated at a rate of 10 euros/hour.

Stimuli. The original stimuli were 40 color face images from four social categories, crossing two races (Asian and Caucasian) with two genders (male and female), as follows: 20 Caucasian faces, and 20 Asian faces; for each race, we used 10 male faces and 10 female faces. All faces had neutral facial expressions and were shown in a frontal pose against a white background.

Design and Procedure. On each trial, participants saw two faces aligned vertically at the center of the screen (see Figure 2B). The task was to indicate the face they saw as bigger by clicking on it with the mouse as quickly as possible. The two faces were displayed until participants clicked on one of them.

Each trial began with a central fixation cross (see Figure 2A). To reduce response biases (e.g., clicking on the closest image to the cursor; Stegner & Cook, 2013), the cursor location was reset to the screen center before the two faces appeared. Participants from Canada and France participated in the experiment online and had to click the fixation cross to see the faces for each trial. In China, where we conducted the study in a lab, the cursor was automatically reset to the center of the screen before the faces were shown. To further reduce predictability and automatic responses, inter-trial intervals varied randomly between 0.5s and 1.5s.

Participants performed three types of trials. In the critical **Top = Bottom** trials, the two faces were identical. We also included two types of catch trials in which the two faces had objectively varied sizes. These trials were to evaluate participant response biases. In the **Top > Bottom** trials, the top face was 8% wider than the bottom image. In the **Top < Bottom** trials, the bottom face was 8% wider than the top one. If participants' responses indexed perceptual processes, they will consistently choose the larger face in catch trials, regardless of whether it appears at the top or the bottom. If participants' responses were biased or random, no difference

should be observed among the **Top = Bottom**, **Top > Bottom**, and **Top < Bottom** trials. The expansion percentage (8%) was determined based on a previous study (Sun et al., 2012), which showed that adults could accurately compare the size of two faces when the size difference between them was larger than 3% of face width.

The experiment included 56 experimental trials, divided into four blocks, corresponding to each face category (Asian female, Asian male, Caucasian female, and Caucasian male). Each block had 10 **Top = Bottom** trials, 2 **Top > Bottom** trials, and 2 **Top < Bottom** trials. The trial order was randomized in each block, and the block order was randomized across participants. Before the experiment started, participants were familiarized with the task via four practice trials using ellipses instead of faces: two of them were the **Top > Bottom** trials, and two were the **Top < Bottom** trials.

The height of each face image was set as 30% of the screen height with the image width adjusted proportionally based on its height. The two faces were presented vertically at the screen center and 16% of screen height above or below the screen center. The gap between the two faces was 2% of the screen height. Participants in China sat in front of a 17-inch (35 cm × 26 cm) computer screen for approximately 60 cm. The two faces and the gap together occupied an area of 7.44° (width) × 15.30° (height) visual angle (from the top edge of the top face to the bottom edge of the bottom face). For online studies, where participants completed the study on their computers, the image size was scaled with the monitor size. We recorded the screen sizes of 31 Canadian participants' monitors the visual angles for the face pair ranged from 5.41° × 11.15° to 10.26° × 21.02°. Despite the variance in stimuli size, we did not find the size affected participants' responses (for details, see supplemental materials).

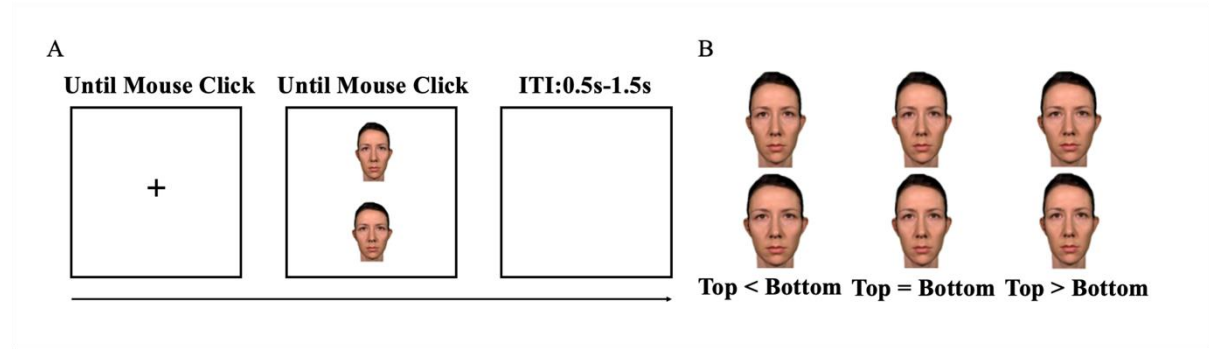


Figure 2. Schematic illustration of a trial (Panel A). And examples of face pairs for each trial type: Top < Bottom, Top = Bottom, and Top > Bottom (Panel B).

1.2. Results & Discussion

In accord with prior studies (Sun et al., 2012, 2013), our dependent variable was the proportion of the responses choosing the bottom face as bigger (i.e., bottom face response rate). In the **Top = Bottom** condition, the expected response rate of bottom choice was 50% because the two images were identical. A response rate significantly above the expected rate indicated the previously documented “Fat Face” illusion.

The prevalence of the “Fat Face” illusion. One-sample *t*-tests against the expected response rate (50%) revealed that, in the **Top = Bottom** trials, participants exhibited a strong bias in choosing the bottom face as bigger across faces of different races and gender, and participants’ countries ($ts > 7.17$, $ps < .001$, *Cohen’s ds* > 1.31; see Figure 3A). The illusion was universal across face category, participants’ face experience, and experimental settings.

To examine participants’ response bias, we compared response rates between the three trial types (**Top = Bottom**, **Top > Bottom**, and **Top < Bottom**) with a repeated-measures one-way ANOVA. The results indicated a significant effect of trial type ($F(2, 180) = 1469.69$, $p < .001$, $\eta_p^2 = .94$). Bonferroni post-hoc tests revealed significant differences for all comparisons (ps

$< .001$, *Cohen's ds* > 1.31 ; **Top = Bottom**: $M = 0.83$, $SD = 0.37$; **Top > Bottom**: $M = 0.09$, $SD = 0.30$; **Top < Bottom**: $M = 0.99$, $SD = 0.10$). This finding suggested that participants' responses reflected perceived differences between conditions. Thus, the illusion was a perceptual effect, rather than a response bias.

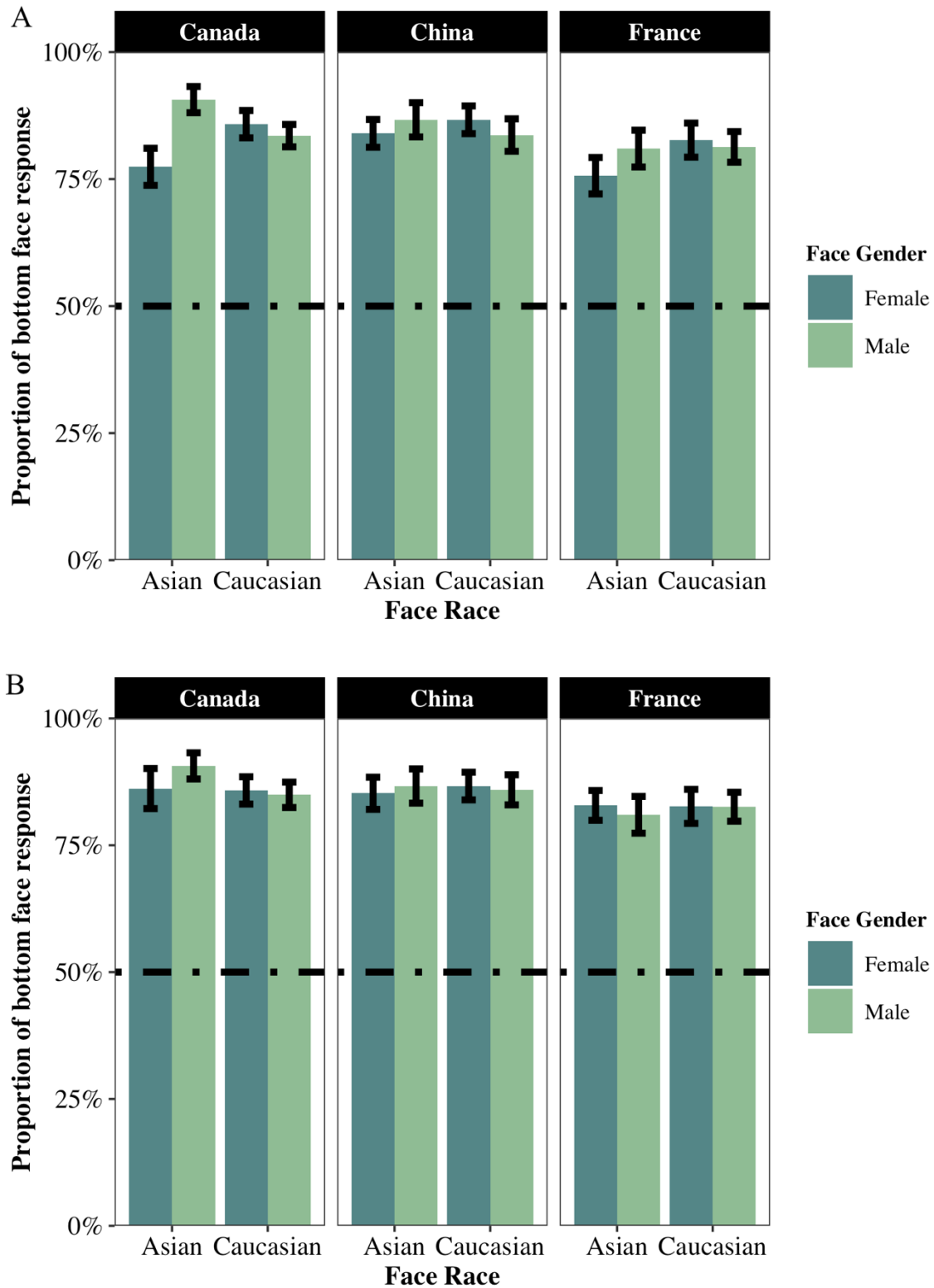


Figure 3. Mean rate of bottom choices for the **Top = Bottom** trials by face categories (race and gender) for the three samples (Canadian, Chinese, and French) in Experiment 1. The dashed lines

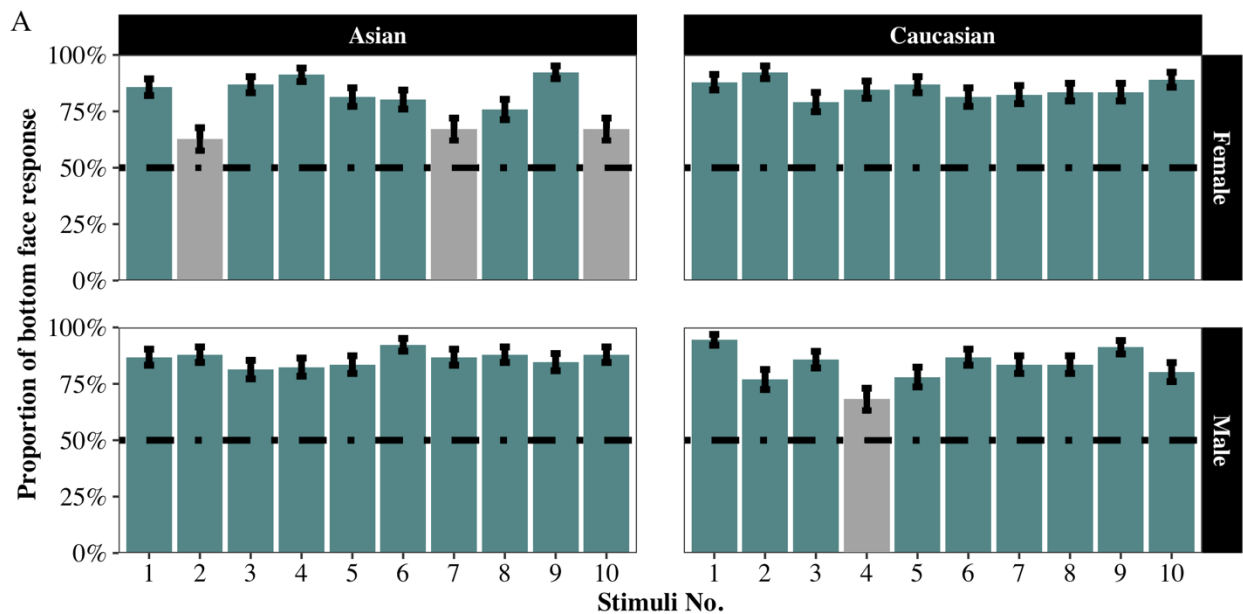
indicate the expected response rate (50%). Error bars indicate one standard error from the mean. Panel A shows the data with all faces. Panel B shows data after excluding idiosyncratic faces (i.e., Asian female faces #2, #7, #10, and the Caucasian male face #4).

Comparable “Fat Face” illusion for different social categories of faces. As shown in Figure 3A, the illusion was much smaller for the Asian female faces than for the Asian male faces, especially in the Canadian sample. To assess gender differences for the Asian faces, we conducted a Paired-sample *t*-test for the Canadian sample. The results confirmed a significant difference ($t(30) = 4.38, p < .001, \text{Cohen's } d = .79$). This effect may originate from: (i) categorical differences, where Asian female faces led to a smaller illusion compared to other face categories; (ii) idiosyncratic items within a category, where individual stimulus from the category of Asian female faces reduced the illusion for the whole category. To tease apart these two possibilities, we performed a Bartlett's test to explore the homogeneity of variance in response rates among the four face categories. The results revealed a significant difference in variance between different categories of faces ($K^2 = 28.85, df = 3, p < .001$), suggesting a large item difference among the faces of a category.

To further explore this possibility, we performed an item analysis within each face category. We compared the size of the illusion with a one-way ANOVA. If images are comparable and representative of the category, they should elicit an illusion comparable in size. By contrast, if an image is not representative of its social category, the illusion will differ in size compared to other items of the same category. This analysis showed a significant effect of item on illusion size for Asian females ($F(9, 810) = 7.43, p < .001, \eta_p^2 = .08$) and Caucasian males ($F(9, 810) = 4.07, p < .001, \eta_p^2 = .04$). It suggested that amongst the Asian female and Caucasian

male faces some items were not representative of their categories. Bonferroni post-hoc tests indicated that Asian female items #2 ($M = 0.63, SD = 0.49$), #7 ($M = 0.67, SD = 0.47$), and #10 ($M = 0.67, SD = 0.47$), and Caucasian male item #4 ($M = 0.68, SD = 0.47$) elicited a smaller illusion than other faces belonging to the same category (see Figure 4A). We found no idiosyncratic items for the other two face categories (Asian male: $F(9, 8810) = .98, p = .451, \eta_p^2 = .01$; Caucasian female: $F(9, 810) = 1.26, p = .253, \eta_p^2 = .01$). Considering these analyses, we concluded that the smaller illusion for Asian female faces was likely due to specific faces.

Rawal and Tseng (2020) showed that faces with a bottom-large geometric shape substantially reduced the “Fat Face” illusion. This finding could help explain the smaller illusion for the Asian female faces because these faces shared some unique idiosyncratic features (i.e., long hair around the neck area, Figure 4B). Long hair alters the canonical shape of a face (i.e., usually having a wider top part than the bottom part), thereby leading to a significantly smaller effect. Similarly, for Caucasian male face #4, which has a bottom-large geometric shape relative to other Caucasian male faces (Figure 4C).



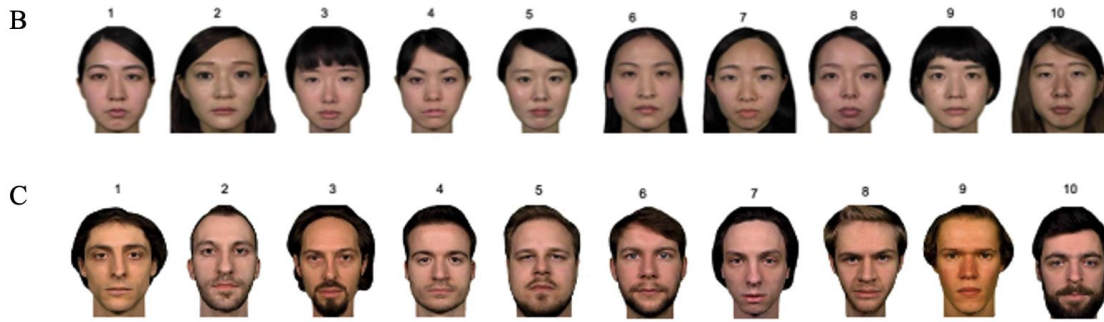


Figure 4. Mean rate of bottom choices for each face image. The faces with significantly smaller illusions within their category appear in gray bars. The dashed lines indicate the expected response rate (50%). Error bars indicate one standard error from the mean (Panel A). The Asian female faces (Panel B) and the Caucasian male faces (Panel C) used in Experiment 1a.

Considering the item analysis, we excluded the four faces with idiosyncratic features from subsequent analyses. A $2 \times 2 \times 3$ mixed ANOVA was performed to examine if *Face Race* (2: Caucasian vs. Asian), *Face Gender* (2: male vs. female), and *Country* (3: Canada vs. China vs. France) affected the responses in the **Top = Bottom** condition. *Face Race* and *Face Gender* were within-subjects variables, and *Country* was a between-subjects variable. This analysis revealed that no main effects or interactions reached significance ($ps > .306$, see Figure 3B, for bottom response rates by country and face categories). As such, we concluded that neither face type (race or gender), nor previous experience with faces (country of participants) affected the size of the “Fat Face” illusion.

Comparable “Fat Face” illusion for different levels of face experiences. To explore the effect of face experience on the illusion, we classified the stimuli into own-race and other-race, based on participants’ ethnicities. For Chinese participants, Asian faces were classified as own-race and Caucasian faces as other-race. The assignment of own- and other-race faces were

reversed for the Caucasian participants. Because the current study only used Asian and Caucasian face stimuli, we included only the Asian ($N = 15$) and Caucasian participants ($N = 11$) from the Canadian sample in our subsequent analysis. The four distinctive face items were excluded from this analysis.

A 2×2 repeated-measures ANOVA with *Face Gender* (2: male vs. female), and *Face Group* (2: own-race vs. other-race) was conducted. The results revealed no significant main effect of *Face Gender* ($F(1, 85) = .02, p = .886, \eta_p^2 < .001$) or *Face Group* ($F(1, 85) = .04, p = .836, \eta_p^2 = .001$). The interaction between the two independent variables did not reach significance ($F(1, 85) = .39, p = .533, \eta_p^2 = .004$). Thus, we found no evidence that the size of the “Fat Face” illusion was modulated by participants’ experience with faces.

2. Experiment 1b

Experiment 1a replicated the “Fat Face” illusion and showed its robustness across different social categories of faces. It, however, also indicated that idiosyncratic facial information (e.g., hairstyle and face shape) may play a crucial role in the perceived size of faces. In our first experiment, removing outliers ensured the homogeneity of the stimuli within each category. It was unclear whether other idiosyncratic facial information may have obstructed differences between facial categories in our first experiment. To corroborate the findings of Experiment 1a, we re-examined the “Fat Face” illusion with a new set of 40 face images. To limit the impact of idiosyncratic facial information (e.g., face shape, hairstyle), all faces were masked by an oval shape, thus sharing an identical contour. By standardizing the contour among face images, any influence of facial categorical information on the perceived face size should

likely reveal. Since no significant difference was found between in-lab and online studies, Experiment 1b was conducted entirely online.

2.1. Methods

Participants. Fifty-one adults (24 females, $M_{\text{age}} = 25.67$ years, $SD = 4.54$ years) participated in this study. Participants were from diverse ethnic backgrounds: 39 Caucasian, 5 African, and 3 Asian. The remaining 4 participants did not disclose their ethnicity. They were recruited online on the academic participant pool Prolific (www.prolific.ac) and were compensated at a rate of 10 euros/hour. Three additional participants' data were removed from the analyses because their responses in the **Top > Bottom** and **Top < Bottom** trials were at chance level (50%).

Stimuli. The original stimuli were 40 colorful face images from four social categories crossing two races (Asian and Caucasian) with two genders (male and female): 20 Caucasian faces and 20 Asian faces. Within each race, 10 were male faces and 10 were female faces. All faces had neutral facial expressions and were shown in a frontal pose.

All face photos were placed in an oval mask. The original face images were expanded or compressed by 3% to generate two face sizes (Sun et al., 2012), which were used in this experiment (Figure 5).

Design and Procedure. The procedure for the “Fat Face” illusion task was identical to that of Experiment 1a. In this experiment, the task included two blocks of 160 trials: 80 **Top = Bottom** trials, 40 **Top > Bottom** trials, and 40 **Top < Bottom** trials.

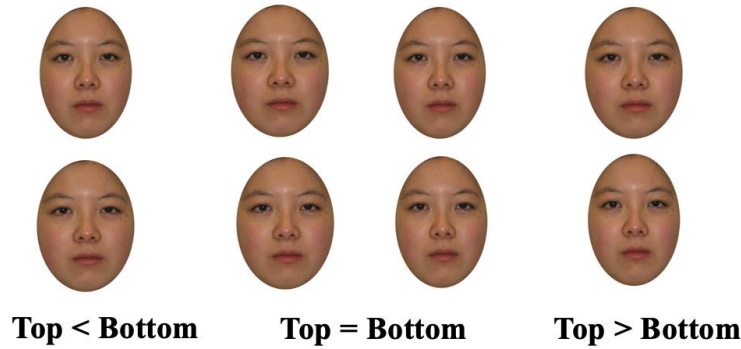


Figure 5. Examples of face pairs for each trial type in Experiments 1b and 2.

2.2. Results & Discussion

The analyses focused on participants' response rate of the bottom face in the **Top = Bottom** condition.

The prevalence of the “Fat Face” illusion. One-sample *t*-tests revealed that, in the **Top = Bottom** trials, participants chose the bottom face as bigger significantly more than the 50% expected response rate for all face categories ($ts > 5.00$, $ps < .001$, *Cohen's ds* > 0.70 ; Figure 6). This result replicated the findings of Experiment 1a, showing that the illusion exists universally across face categories.

To examine if the illusion was due to a response bias (e.g., a tendency to select the bottom face), we compared responses between the three trial types (**Top = Bottom**, **Top > Bottom**, and **Top < Bottom**). A repeated-measures one-way ANOVA revealed a significant effect of trial type ($F(2, 100) = 958.96$, $p < .001$, $\eta_p^2 = .95$). Bonferroni post-hoc tests showed significant differences for all comparisons ($ps < .001$, *Cohen's ds* > 2.97 ; **Top = Bottom**: $M = 0.66$, $SD = 0.36$; **Top > Bottom**: $M = 0.07$, $SD = 0.25$; **Top < Bottom**: $M = 0.97$, $SD = 0.17$). This indicated that participants responded based on their perception of the stimuli. Thus, the illusion was unlikely to be driven by a response bias.

Comparable “Fat Face” illusion for different face categories. To assess whether the illusion was influenced by face categories, a 2×2 repeated-measures ANOVA was performed. We examined if *Face Race* (2: Caucasian vs. Asian) and *Face Gender* (2: male vs. female) affected the response rates in the **Top = Bottom** trials. Both *Face Race* and *Face Gender* were within-subjects variables. The results showed no significant main effects of *Face Gender* ($F(1, 50) = 0.02, p = .887, \eta_p^2 < .001$), or *Face Race* ($F(1, 50) = 2.17, p = .147, \eta_p^2 = .04$). The interaction between the two variables failed to reach significance, $F(1, 50) = 0.01, p = .939, \eta_p^2 < .001$. These results were consistent with those of Experiment 1a, showing that the illusion was not affected by facial categorical information.

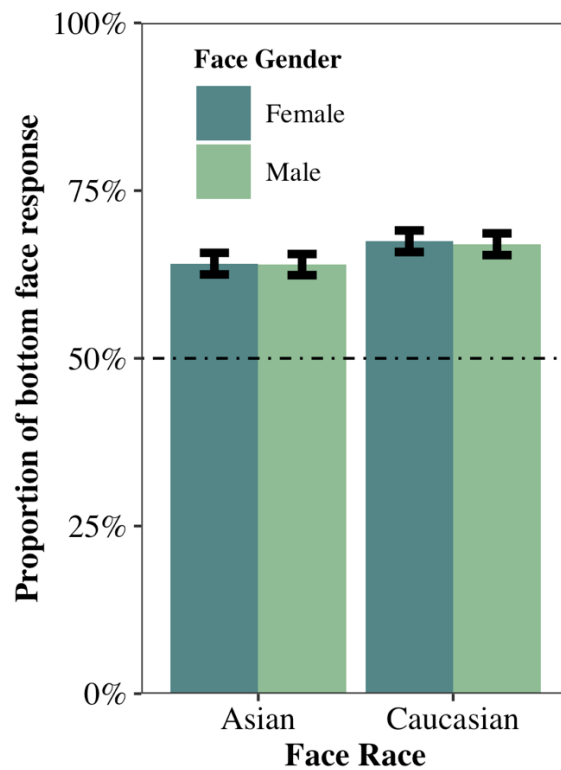


Figure 6. Mean response rate of bottom choices for the **Top = Bottom** trials by face categories. The dashed lines indicate the expected response rate (50%). Error bars indicate one standard error from the mean.

Comparable “Fat Face” illusion for own- and other-race faces. A *Face Gender* (2: male vs. female) by *Face Race* (2: own-race vs. other-race) repeated-measures ANOVA was performed. Given that most participants were Caucasian, we only included these participants ($N = 39$) in the analysis. Asian faces were labeled as other-race, and Caucasian faces as own-race. The results revealed no significant main effect of *Face Gender* ($F(1, 38) = 0.05, p = .826, \eta_p^2 < .01$), *Face Race* ($F(1, 38) = 2.44, p = .127, \eta_p^2 = .06$), nor a significant interaction ($F(1, 38) = 0.28, p = .601, \eta_p^2 < .01$). In accord with Experiment 1a, we showed that the illusion was not modulated by participants’ face experience.

3. Experiment 1c

The results of Experiments 1a and 1b showed that the “Fat Face” illusion emerged for faces from different face categories, suggesting the illusion was a robust phenomenon. Though we included the **Top > Bottom** and **Top < Bottom** trials to evaluate if participants’ responses indexed a perceptual effect, we cannot rule out the possibility of unconscious response biases in the **Top = Bottom** trials. For example, clicking on the bottom face may have been easier or a default response, and participants may have chosen the easier response whenever it was difficult to decide which face was bigger. To rule out this possibility, in Experiment 1c, we asked participants to indicate which face was smaller. If the illusion indexes a perceptual bias, participants should show a bias for choosing the top face in this task. Alternatively, participants should continue choosing the bottom face if the illusion captures a response bias.

3.1. Methods

Participants. A total of thirty-one Canadian participants were recruited (6 males, 24 females, one participant did not disclose their gender, $M_{\text{age}} = 18.23$ years, $SD = 0.62$ years). Participants were from diverse ethnic backgrounds, including 15 Asians, 9 Caucasians, 5 Arabs, 1 African, and one participant who did not disclose ethnicity. All participants were university students and were given course credit for participation.

Stimuli and procedure. The face stimuli and procedure were identical to those in Experiment 1a, except participants were required to indicate which face was smaller.

3.2. Results

We analyzed participants' response rates for top face choices. To ensure the consistency between Experiments 1a and 1c, we excluded the 3 Asian female and 1 Caucasian male faces with idiosyncratic features, as discussed in Experiment 1a.

Table 1 showed the means and standard errors of response rates for the face categories. We found that response rates in all 4 face categories were significantly higher than the expected response rate (50%, One-sample t -test, $t_s > 8.06$, $p_s < .001$, *Cohen's ds* > 1.45). Participants were biased to choose the top face as smaller, suggesting that the bias was a perceptual effect.

Table 1. Mean response rates of top face choices (standard error reported in the parentheses) in the **Top = Bottom** trials for different face categories in Experiment 1c.

Face Race	Facial Gender	Response Rate (SE)
Asian	Female	0.88 (0.03)
	Male	0.84 (0.04)
Caucasian	Female	0.82 (0.03)

Male	0.82 (0.04)
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We compared responses between the three trial types to examine if participants' choices indexed a general bias towards choosing the top face. A repeated-measures one-way ANOVA revealed a significant effect of Trial type ($F(2, 60) = 563.56, p < .001, \eta_p^2 = .95$). Bonferroni post-hoc tests showed significant differences between all comparisons ($ps < .001, Cohen's ds > 1.29$; **Top = Bottom**: $M = 0.84, SD = 0.19$; **Top > Bottom**: $M = 0.05, SD = 0.21$; **Top < Bottom**: $M = 0.99, SD = 0.09$). These results confirmed participants' responses reflected their perceptual processing.

To assess whether face category modulated the illusion, we conducted a repeated-measures ANOVA with *Face Race* (2: Caucasian vs. Asian) and *Face Gender* (2: male vs. female) as within-subject independent variables. The results showed that neither *Face Race* ($F(1, 30) = 1.51, p = .229, \eta_p^2 = .05$) nor *Face Gender* ($F(1, 30) = 0.56, p = .461, \eta_p^2 = .02$) affected participants' responses in the **Top = Bottom** condition. The interaction between the two independent variables did not reach significance ($F(1, 30) = 0.81, p = .376, \eta_p^2 = .03$). These results corroborated our previous findings suggesting that the face categories did not influence the illusion.

Lastly, to probe whether task requirements (choosing the bigger face vs. choosing the smaller face) modulated participants' responses, we conducted a mixed ANOVA to compare the results of Experiments 1a and 1c. Only the Canadian sample from Experiment 1a was included in this analysis. *Face Race* (2: Caucasian vs. Asian) and *Face Gender* (2: male vs. female) were

within-subject variables, and *Task Requirement* (2: Bigger response vs. Smaller response) was a between-subject variable. No main effects or interaction reached significance ($ps > .093$), indicating that participants' responses were consistent across the two task requirements, further strengthening the conclusion that the illusion is a perceptual effect.

3.3. Discussion

Experiments 1a, 1b, and 1c consistently replicated the “Fat Face” illusion. Moreover, Experiment 1a demonstrated the robustness of the “Fat Face” illusion, which appeared regardless of face categorical information (i.e., race and gender). In addition, the illusion was comparable across participants from different countries, despite differences in experimental environments (e.g., laboratory vs. online studies).

In Experiment 1b, we replicated our first experiment using faces masked by an oval shape, for two reasons. First, to ensure that any effect of face categorical information on the illusion was not occluded by idiosyncratic differences between faces (e.g., hair length or face shape). Second, to confirm the face-specificity of the “Fat Face” illusion, we removed any geometric cues that may have induced the illusion. Previous research proposed that this type of perceived size illusion was primarily generated by the geometric shape of the face (top wide bottom narrow) and that any non-face objects with this configuration could cause the illusion (Rawal & Tseng, 2020). Here, even when faces were masked by oval shapes, participants showed the same illusion. These results suggest that the illusion is highly robust and indicate that the geometric shape of the face is not a necessary feature for the illusion to be perceived. However, it is worth noting that the illusion was larger for unmasked faces (Experiment 1a: $M = 0.85$, $SD = 0.17$ and Experiment 1c: $M = 0.84$, $SD = 0.19$) than for oval masked faces ($M = 0.66$,

$SD = 0.36$, Experiment 1b). Consistent with previous findings, this shows that face shape plays a role, but is not indispensable, for the “Fat Face” illusion (Rawal and Tseng, 2020; Sun et al., 2013). Although the top wide, bottom narrow geometric shape was removed, and the size of the illusion was reduced (Sun et al., 2013), the face concept was sufficient to trigger this illusion.

All the results from Experiment 1 indicate that individual experience with a particular face category (i.e., own-race vs. other-race faces) does not affect the illusion. This implies that the “Fat Face” illusion may not depend on experience with a specific face category. The stability of this perceptual effect suggests that this illusion may index a fundamental capacity of our visual system for representing multiple faces in the environment.

4. Experiment 2

In Experiment 2, we explored the mechanism of the robust “Fat Face” illusion by testing its dependence on binocular vision. We hypothesized that the vertical layout of faces creates a depth cue for our face processing system, such that the bottom face is perceived as closer to an observer than the top one. Thereby, the closer face (i.e., the bottom face) is also perceived as bigger than the more distant face (i.e., the top face). For example, in a group photo where faces are aligned vertically, the person at the bottom is generally closer to observers, than the person at the top. Thus, our visual system may be tuned to the spatial layouts of faces in our environment and use them to infer proximity to others. Because we primarily use both eyes to perceive distance information in our environment, binocular vision plays a dominant role in depth discrimination in natural environments (e.g., Allison et al., 2009). Considering the vertical layout represents a subtle difference in the proximity of people, monocular vision might be too weak to

detect this subtle difference in depth. To test this hypothesis, we asked participants to perform the “Fat Face” illusion task in two conditions: monocular vision and binocular vision.

4.1. Methods

Participants. Twenty-four Chinese adults (13 females, $M = 20.75$ years, $SD = 2.05$ years) participated in this study and were randomly assigned to either the binocular condition ($N = 12$, 7 females, $M = 21.5$ years, $SD = 1.93$ years), or the monocular condition ($N = 12$, 6 females, $M = 19$ years, $SD = 1.23$ years). They were university students, who performed the experiment in the laboratory and were remunerated with course credit for their participation.

Stimuli, Design and Procedure. Since we found no difference in the illusion for Asian and Caucasian faces, we used the 20 Asian faces (10 males) from Experiment 1b. Because this experiment required procedures (e.g., eye dominance assessments and covering one eye) that were difficult to execute online, Experiment 2 was performed in a lab.

For the monocular group, two eye dominance assessments were run before the “Fat Face” illusion task. In *the Hole-in-Card Test* (The Dolman Method, Durand & Gould, 1910; Li et al., 2010), participants were asked to use both hands to hold a card at arm's length. The card had a 3 cm hole in the middle. An object was placed 6 m away from the participants. First, they needed to see the object through the hole in the card with both eyes open. Then, participants were asked to use one eye at a time to locate the same object. The eye that could still see the object was considered their dominant eye. The second assessment was *the Simple Pointing Test* (Goldberg & Wichansky, 2003). Participants were instructed to point at a distant target using their right index fingers with both eyes open. While holding the position, they were required to close one eye at a time. The eye that could see the index finger point directly to the target was the

dominant eye. The two assessments reached 100% agreement on determining the dominant eye for all participants.

After completing the eye dominance assessments, participants performed the “Fat Face” illusion task with one eye covered by an opaque cloth. Half of the participants started the experiment with their dominant eye open, then switched to the non-dominant eye open for the second half of the experiment. The order of dominant/non-dominant eye usage was counterbalanced across participants. The task included two blocks of 320 trials: 160 **Top = Bottom** trials, 80 **Top > Bottom** trials, and 80 **Top < Bottom** trials.

For the binocular group, the “Fat Face” illusion task included two blocks of 160 trials: 80 **Top = Bottom** trials, 40 **Top > Bottom** trials, and 40 **Top < Bottom** trials. Thus, the number of trials for each eye for the monocular group was the same as the total number of trials for the binocular group.

4.2. Results and Discussion

First, we compared participants’ bottom face response rate between the monocular and binocular groups when the two faces were identical (the **Top = Bottom** trials). For the monocular group, we did not find any difference between the dominant ($M = 0.51$, $SD = 0.17$) and non-dominant eye ($M = 0.49$, $SD = 0.13$, *Paired-sample* $t(11) = 0.47$, $p = .644$, *Cohen’s* $d = 0.14$). Thus, we averaged participants’ response rate across the dominant and non-dominant eye trials. An independent-sample *t*-test comparing response rates between the monocular and binocular groups revealed that participants exhibited stronger bottom face responses when binocular vision was available ($M = 0.69$, $SD = 0.33$), compared to when monocular vision was available ($M = 0.50$, $SD = 0.38$; $t(22) = 3.73$, $p = .001$, *Cohen’s* $d = 1.59$, Figure 7).

Within each group (monocular and binocular vision), we compared the proportion of bottom face response against the expected response rate (50%). The results showed a significant illusion in the binocular condition ($t(11) = 5.68, p < .001, \text{Cohen's } d = 1.64$). By contrast, participants showed no bias to choose any faces in the monocular condition ($t(11) = 0.10, p = .929, \text{Cohen's } d = 0.03$).

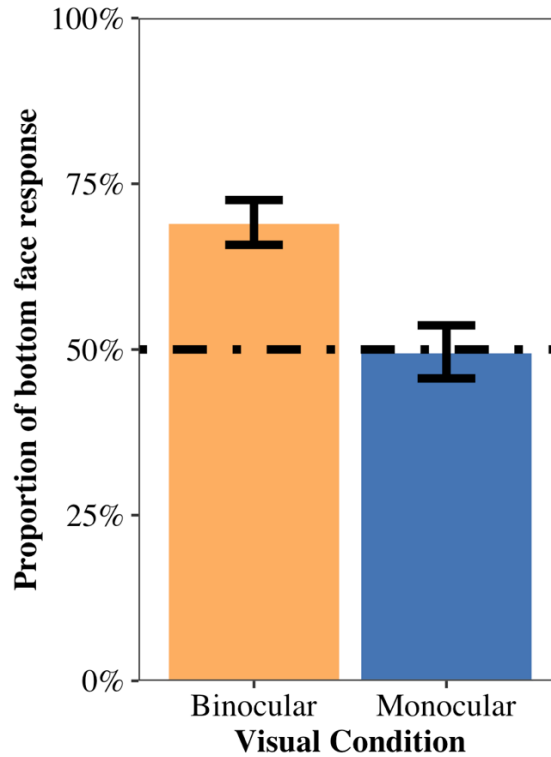


Figure 7. Mean rate of bottom choices for the **Top = Bottom** trials for the binocular and monocular groups in Experiment 2. The dashed line represents the expected response rate (50%). Error bars indicate one standard error from the mean.

Finally, we assessed whether the response difference between the monocular and binocular conditions in the **Top = Bottom** trials indexed a perceptual process or response bias (e.g., participants in the monocular condition were less likely to choose the “bottom” face). To this end, we compared the response rate between the monocular and binocular groups in the **Top**

< **Bottom** and **Top** > **Bottom** trials with Independent-sample *t*-tests. The results showed comparable response rates between the monocular and binocular groups for the **Top** < **Bottom** trials (Monocular: $M = 0.97$, $SD = 0.13$; Binocular: $M = 0.98$, $SD = 0.07$, $t(22) = 2.12$, $p = .05$, *Cohen's d* = 0.91), and for the **Top** > **Bottom** trials (Monocular: $M = 0.05$, $SD = 0.16$; Binocular: $M = 0.08$, $SD = 0.19$; $t(22) = 0.95$, $p = .353$, *Cohen's d* = 0.40). These results indicate that the difference between the monocular and binocular groups was specific to the **Top** = **Bottom** trials. This suggests that binocular vision is essential for this face-specific perceived size illusion to appear. Given the significant role of binocular vision in perceiving depth information, our finding indicates that the visual system treats the vertical layout of faces as a depth cue, which in turn augments the perceived size of the closer individual and results in the “Fat Face” illusion.

5. General Discussion

Faces are processed as special objects by the human visual system, and multiple functional adaptations have been documented for processing individual faces, such as holistic face processing (Richler & Gauthier, 2014; Tanaka & Gordon, 2011). Recent evidence suggested that specialized mechanisms may exist for processing multiple faces. A human face-specific “Fat Face” illusion has been reported for vertical displays of two faces, one on top of the other, which magnify the perceived size of the bottom face compared to the top one (Sun et al., 2012, 2013). The current study investigated the nature and mechanism of the “Fat Face” illusion and allows us to report two main findings.

First, our results highlighted that the “Fat Face” illusion was robust, which was regardless of facial categories, face experiences, presentation formats, task requirements, and experimental

settings. The generalization of this illusion and its immunity to the experience with a face category contrasted other cognitive capacities specific to faces. For instance, holistic face processing is impaired by infrequently experienced faces, such as other-race faces, but also by uncommon orientations, such as inverted faces (e.g., Michel et al., 2006; Zhao et al., 2014). The stability of the “Fat Face” illusion for infrequent types of faces suggests that the activation of the face concept may suffice to activate this illusive perception, which is less affected by face categorical information. The “Fat Face” illusion resembles some human face-specific phenomena observed early in life, such as the predisposition for faces, which is not shaped by experience either. Newborns orient towards and look longer at face-like configurations, compared to other nonface stimuli matched in complexity (Goren et al., 1975; Johnson et al., 1991; Valenza et al., 1996). Our findings raise important implications about the nature of this adaptation for processing multiple faces, suggesting that the “Fat Face” illusion may also be present at early stages of life. Future developmental studies are essential to help understand the origin of our abilities to process multiple faces.

It is important to note that previous studies have established the “Fat Face” illusion as a face-specific phenomenon, which suggests that the illusion can only be perceived with upright face images. Previous studies have proved the face-specificity with several lines of evidence. First, when faces were covered with oval masks to remove the visual cue of face shapes, the illusion still existed (Expt 1b, Sun et al., 2012). However, the illusion disappeared when images of other visual categories with similar shapes (e.g., clocks) were presented (Sun et al., 2012). Second, Tomonaga (2015) reported that chimpanzees were immune to the “Fat Face” illusion, although both chimpanzees and humans were equally susceptible to the Jastrow illusion, an illusion with a similar layout but using curved lines instead of faces. This contrast between

humans and chimpanzees suggests that the “Fat Face” illusion is unlikely to result from a mere comparison between the lower and upper edges of the faces and may rely on human-specific face processing mechanisms, not shared by our closest neighbor in the evolutionary tree. Moreover, by presenting inverted faces, though the geometric shape was inverted (top narrow and bottom wide), no inverted illusion was found (Sun et al., 2012). Lastly, but most evidently, the illusion still appeared when were presented face without contours (i.e., the normal layout of internal facial features, Sun et al., 2013). Together, these findings strongly suggest that the “Fat Face” illusion is driven by the conceptual representation of faces.

The face-specificity of the “Fat Face” illusion also makes it distinctive from other classical visual illusions (e.g., Ponzo illusion). In the Ponzo illusion, the two converging lines which provide a “pictorial depth cue” are significant to induce the illusion (*sensory-driven bottom-up signal*). However, there is no such pictorial visual element that indicates the depth information in the “Fat Face” illusion. The depth perception is activated by our representation of how faces usually appear in the environment (*concept-driven top-down signal*). The face-specificity suggests that this phenomenon does not merely capture a generic mechanism for size estimation but indexes a type of processing specific to social interactions. In accord with this argument, the human visual system may be specifically adapted to judging relative size in the social domain: a crucial aspect of social perception, which informs humans about potential social interactions or external threats in the physical world (Adams et al., 2011; Balcetis & Lassiter, 2010; Bruner & Goodman, 1947).

Another main finding was that binocular vision was critical for the “Fat Face” illusion. The binocular dependency appeared counterintuitive at first glance because the two faces were presented on the same vertical plane (i.e., a monitor), and the size judgement task could be

achieved with monocular vision. Neither the presentation of faces nor the task requires binocular vision, and monocular vision can achieve equivalent or sometimes even better performance than binocular vision in similar tasks (e.g., Song, Schwarzkopf, & Rees, 2011). These seemingly discrepancies strongly imply that the “Fat Face” illusion represents a process beyond the perception of face size. And our interpretation is that our visual system possesses a special representation for the vertical layout of faces. Specifically, the verticality signifies proximity to the faces, where the face higher in the picture plane is perceived more distant from the viewer and appears smaller in size and vice versa for the face in the lower picture plane. This face-specific representation depends on binocular vision because we rely on both eyes to perceive depth information in our environment (e.g., Mckee and Taylor, 2010). As we develop the representation of relative spatial relations among faces, binocular vision becomes a necessity of the representation. When binocular vision was disrupted (i.e., monocular vision), the representation could not be activated, therefore leading to an absence of the illusion. In sum, the binocular dependency suggests that our visual system uses spatial layouts of faces to implicitly infer the relative proximity of faces in the environment.

Our data suggests that our visual system implicitly uses the vertical display of faces to infer their relative proximity. However, why would the perceived proximity modulate the perception of face size? One possibility is that the face perceived as closer to the observer carries a higher social value and is thus perceived as larger. Recent studies have shown associations between social relevance and perceived size. For instance, the size of objects with high self-relevance (e.g., high value to the perceiver) was consistently overestimated (Anton-Erxleben et al., 2007; Dubois et al., 2010; Kirsch et al., 2018). Self-face was perceived as significantly larger than another face of the same physical size because of the unique connection between our face

and our sense of identity (Zhang et al., 2021). Likewise, objects that are crucial for attaining a highly desired goal are perceived as larger (Veltkamp et al., 2008). In our study, the bottom face may be perceived as more socially relevant due to its increased perceived proximity, leading to an enlarged perceived size.

This illusion further represents an adaptive strategy of our visual system for allocating cognitive and attentional resources to the most important signals (i.e., the individual closest to us) in the environment. This proposal is supported by studies showing that larger stimuli receive prioritized processing and attention (Nah et al., 2018; Proulx & Green, 2011; Wolfe & Horowitz, 2017). If the “Fat Face” illusion is indeed an adaptation aimed at detecting the most relevant individuals in the environment, then the size of the illusion may be strongly modulated by any indication of self-relevant signals, including facial expressions and aggressive facial traits. This speculation can be supported by the finding that self-irrelevant objects (e.g., clock) failed to give rise to the illusion (Sun et al., 2012).

It should be noted that the absence of the illusion under monocular vision might be explained by a generally inferior perception with monocular as opposed to binocular vision. It is widely acknowledged that binocular vision leads to stronger and stabler perception than monocular vision in various visual tasks. Judging which face was larger with monocular vision (Experiment 2) might have been challenging for detecting the illusory differences in face sizes. This alternative explanation entails that those differences in the current study observed between binocular and monocular vision are not because of the inaccessibility to the stereopsis representation. While this explanation appears plausible, our findings do not support it. Firstly, we found a difference between binocular and monocular vision only in the **Top = Bottom** trials. In the **Top > Bottom** and **Top < Bottom** trials, participants performed equally well regardless of

the use of the eyes. In other words, our data does not support the interpretation of a general impairment under monocular vision. Secondly, in the monocular vision condition, we compared participants' performance with the dominant versus non-dominant eye, but no difference was observed between the two. Given that the dominant eye is superior to the non-dominant eye in visual processing (e.g., Porac & Coren, 1976; Shneur & Hochstein, 2005), the similar performance between the two eyes in the current study suggests that the task is not demanding and even using the non-dominant eye can reach the same level of performance as what can be achieved with the dominant eye. Lastly, we argue that the disappearance of the illusion in the monocular vision condition was not because the monocular vision was less stable than binocular vision. As indicated by the size of the error bars in Figure 7, the monocular and binocular groups in Experiment 2 demonstrated equivalent variance, suggesting that binocular and monocular vision were equally stable in the current task. In sum, our data do not support an interpretation based on the inferiority of monocular vision compared to binocular vision. In fact, in our study, monocular vision led to a more objective and faithful perception of the visual stimuli. The additional information available under binocular vision, however, induced the illusory perception. As discussed above, to further evaluate the relation between the perception of face proximity and the "Fat Face" illusion, future studies may examine how faces varying in perceived proximity (e.g., threatening individuals are perceived closer) modulate the illusion.

6. Conclusion

Collectively, these results suggest that the human visual system presents important functional adaptations not only for processing individual faces but also for processing relations

between multiple conspecific faces. This adaptive mechanism may represent an efficient strategy for estimating the size of social partners or potential social threats and may appear early in life.

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