Running Head: VISUAL EXPERTISE AND CROWDING

Chinese-reading Expertise Modulates the Crowding Effect of Chinese Characters on Face
Categorization

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Abstract

Crowding refers to the inability to recognize an object in peripheral vision when other objects are presented nearby. Studies have shown that crowding can be influenced by both low-level visual features and high-level object representations. In the current study, we tested how visual expertise affects crowding. We had native Chinese and non-Chinese readers perform a gender categorization task, in which they categorized target faces flanked by faces or Chinese characters that were presented upright or inverted. The results showed an effect of target-flanker similarity on crowding, as all participants performed worse when target faces were crowded by face compared to Chinese character flankers. The results also showed that native Chinese readers, but not non-Chinese readers, experienced more crowding when target faces were surrounded by upright compared to inverted face or Chinese character flankers, suggesting that participants' visual expertise with the flanking stimuli along with their perceptual processing style shaped by cultures play an influential role in modulating the crowding effect. Our results support recent research showing that crowding is susceptible to both low- and high-level visual information.

Introduction

Crowding refers to the difficulty in identifying an object in peripheral vision when other objects are presented nearby (for reviews, see Levi, 2008; Pelli & Tillman, 2008; Whitney & Levi, 2011). Crowding has been demonstrated with a wide range of stimuli, such as line segments (Bulakowski, Post, & Whitney, 2009; Manassi, Sayim, & Herzog, 2012, 2013), symbols (Grainger, Tydgat, & Issel, 2010), letters (e.g., Freeman, Chakravarthi, & Pelli, 2012), words (Yu, Akau, & Chung, 2012), faces (Farzin, Rivera, & Whitney, 2009; Louie, Bressler, & Whitney, 2007; Sun & Balas, 2015), and biological motion stimuli (Ikeda, Watanabe, & Cavanagh, 2013). While the phenomenon of crowding has been well described in the literature, the mechanisms that give rise to crowding remain controversial. Many theories have been proposed to account for crowding, ranging from large peripheral receptive fields (Levi & Waugh, 1994), to excessive featural integration of the peripheral target and flankers for object recognition (Pelli & Tillman, 2008), compulsory averaging of the target and flankers for texture perception (Parkes, Lund, Angelucci, Solomon, & Morgan, 2001; (Balas, Nakano, & Rosenholtz, 2009), and reduced resolution of spatial attention in the periphery (He et al., 1996). It has also been suggested that crowding not only occurs at an early stage of visual processing, such as where the binding of low-level visual features happens (e.g., Parkes et al., 2001; Pelli, Palomares, & Majaj, 2004; Tripathy & Cavanagh, 2002), but also occurs at higher stages of visual processing, such as where object representations are formed (e.g., Farzin et al., 2009; Ikeda, Watanabe, & Cavanagh, 2013; Louie et al., 2007; Reuther & Chakravarthi, 2014; Sun & Balas, 2015).

Based on the results of these studies, several characteristics of crowding have been identified. For example, crowding increases with increasing target eccentricity and therefore is

particularly robust in peripheral vision. At a given eccentricity, crowding decreases with increasing distance between the target and flankers; identification of a crowded target improves when the spacing between the target and flankers is larger than half of the target eccentricity (the Bouma law; Bouma, 1970). Crowding is stronger when the flanker is on the more eccentric side of the target compared to when the flanker is on the side of the target that is nearer to the fovea (Bouma, 1970; Petrov, Popple, & McKee, 2007). Increasing flanker complexity or target-flanker similarity also increases crowding (Bernard & Chung, 2011; Kooi, Toet, Tripathy, & Levi, 1994). Crowding is also affected by grouping between the target and flankers, such as a red vernier amongst green lines produces less crowding than amongst red lines (Manassi, Sayim, & Herzog, 2012).

Additionally, studies have shown that crowding is influenced by visual experience. For example, participants' performance in identifying crowded letters is improved after training on identification of flanked letters in the periphery (e.g., Chung, 2007; Huckauf & Nazir, 2007; Sun, Chung, & Tjan, 2010). Crowding effects are smaller for letters than for symbols, presumably due to the modified size of the crowding region for letters in words during reading acquisition (Grainger et al., 2010). Music-reading experts show a smaller crowding effect than novices when they are asked to identify the location (on a line or on a space) of a crowded music note, but not when they are asked to identify the location of the gap of a crowded Landolt C (Y. K. Wong & Gauthier, 2012). Crowding is smaller when an upright target face is surrounded by inverted compared to upright faces, presumably due to the loss of our normal proficiency at face perception (and thus less interference) when faces are inverted (Farzin et al., 2009; Louie et al., 2007). In contrast, non-face object recognition is not sensitive to inversion; crowding of house targets by house flankers is not affected by flanker's orientation (Louie et al., 2007). This is

consistent with research showing that inversion affects the processing of faces more than other objects (e.g., Freire, Lee, & Symons, 2000; Yin, 1969).

However, it is still unclear whether the effect of flanker orientation on target recognition can be generalized across different objects of expertise. Research has suggested that faces seem special because people have had more experience of individuating them compared to that of individuating other objects (the expertise hypothesis, e.g., Diamond & Carey, 1986; Gauthier & Tarr, 1997). The intensive experience of recognizing faces leads to holistic face processing, as evidenced by the face inversion effect (Yin, 1969) as well as the composite face effect (Young, Hellawell, & Hay, 1987). Nonetheless, although configural processing is shown to be a behavioral hallmark of face processing (e.g., Maurer, Le Grand, & Mondloch, 2002), visual expertise also increases configural processing of non-face stimuli, such as dogs (Diamond & Carey, 1986), cars (Gauthier, Skudlarski, Gore, & Anderson, 2000), musical notes (Wong & Gauthier, 2010), novel objects (e.g., Greebles; Gauthier & Tarr, 1997), English words (Wong et al., 2011), and Chinese characters (e.g., Kao, Chen, & Chen, 2010; Wong et al., 2012; but see Hsiao & Cottrell, 2009). For example, Diamond and Carey (1986) demonstrated that while both dog experts and novices showed a large recognition decrement with inverted compared to upright human faces, only dog experts showed worse performance in recognizing inverted compared to upright dog pictures. Wong et al. (2011) had native English readers perform a composite task and found that matching the target parts of an English word was interfered by the irrelevant parts unless the two parts were misaligned, demonstrating the importance of holistic processing in word perception [see Wong et al. (2012) for a similar finding using Chinese characters]. Kao et al. (2010) also showed that Chinese readers had more difficulty identifying inverted compared to upright Chinese characters, presumably due to the disruption of configural

processing caused by inversion. Therefore, it is possible that non-face objects of expertise would affect crowding in terms of a flanker inversion effect showing more crowding when targets are surrounded by upright compared to inverted distractors.

The main purpose of the present study was to examine the role of visual expertise in crowding using different classes of objects and varying levels of expertise with these stimuli. Specifically, we used expertise with faces and Chinese characters as a means of studying this aspect of visual crowding. We recruited native Chinese and non-Chinese readers to perform a face categorization task, in which they indicated the gender of a target face that was either presented alone or surrounded by face or Chinese character flankers. We expected that face flankers would impair performance more than Chinese character flankers because crowding increases with target-flanker similarity (e.g., Bernard & Chung, 2011). We also manipulated flanker orientation to assess the influence of higher-level object representations as well as low-level visual properties on crowding. Given that configural processing emerges with perceptual expertise and inversion produces impairments in processing configural information (Gauthier, Curran, Curby, & Collins, 2003; Rossion, Gauthier, Goffaux, Tarr, & Crommelinck, 2002), we expected that upright face flankers would impair target categorization more than inverted face flankers for both native Chinese and non-Chinese readers. Additionally, we expected that only native Chinese readers, but not non-Chinese readers, would show a stronger crowding effect when the target face was flanked by upright compared to inverted Chinese characters.

Experiment 1

Methods

Participants

Nineteen native Chinese readers (7 males, 12 females) and 20 non-Chinese readers (10 males, 10 females) from North Dakota State University participated in the study for course credit or monetary compensation. The mean age of the native Chinese readers was 20.4 years, and all of them were born in Taiwan, mainland China, or Malaysia. The mean age of the non-Chinese readers was 19.2 years, and all of them were Caucasians. All participants had normal or correct-to-normal vision and were naïve to the purpose of the study. The experimental protocol was approved by the North Dakota State University Institutional Review Board for the protection of human participants in research, and informed consent was obtained from all participants.

Apparatus

Participants were tested individually in a room with the lights off. The stimuli were presented on an 18-inch CRT monitor with a 75-Hz refresh rate. A chin rest was used to maintain a constant viewing distance of 60 cm. Responses for the experimental trials were collected through the computer keyboard. The experiment was programmed in MATLAB, using the Psychophysics Toolbox extensions (Brainard, 1997; Pelli, 1997).

Stimuli

Twenty-two front-view Caucasian faces (11 males, 11 females) with neutral expressions were selected from the grayscale Face Recognition Technology (FERET) database (http://www.itl.nist.gov/iad/humanid/feret/feret_master.html). Sixteen of these faces were used as targets (8 males, 8 females), and the remaining six were used as flankers (3 males, 3 females).

Six Chinese characters (深, 取, 電, 之, 名, 少, meaning “deep”, “obtain”, “electricity”, “of”, “name”, and “few”, respectively) were also selected to serve as another set of flanker stimuli; all were frequently used Chinese characters according to Zhang, Zhang, Xue, Liu, and Yu (2009). During the experiment, target faces were either presented alone or surrounded by six flankers. Within a trial, all flankers were always presented in the same orientation (i.e., upright or inverted) and all were from the same stimulus category (i.e., faces or Chinese characters). Width and height of the stimuli were 65×80 pixels, corresponding to a visual angle of $2.18^\circ \times 2.69^\circ$ at a viewing distance of 60 cm. In the flanked condition, the center-to-center distance between target and flanker was fixed at 2.52 deg. During the experiment, all stimuli were presented on a gray background. Figure 1 shows examples of the stimuli in different experimental conditions.

Figure 1. Left: The sequence of events within a trial in which the target face appeared to the left of the fixation in Experiment 1. Right: Example stimuli for different combinations of flanker type (face, Chinese character) and orientation (upright, inverted). All images depict trials in which a target face and its flankers appeared on the left side of the screen.

Procedure and design

Each trial began with a fixation point (a 0.34° square) presented at the center of the computer screen for 500 ms. Next, a target face with or without flankers was presented at the fovea (0° eccentricity) or at 6° to the left or right of fixation for 200 ms, followed by a blank screen for 500 ms and then a question mark. The question mark remained visible on the screen until the participant responded. Participants categorized target faces as male or female by pressing the left or right arrow key on the computer keyboard; response time was unlimited. If the participants were uncertain about the target face's gender, they were instructed to make a guess. No feedback was provided after each response. Figure 1 illustrates the sequence of events in each trial.

The experiment used a 3 (target eccentricity: -6° , 0° , 6°) $\times$ 2 (flanker type: face, Chinese character) $\times$ 2 (flanker orientation: upright, inverted) factorial design. Participants completed 32 trials per condition, for a grand total of 384 trials with flankers present and an additional set of 192 trials (64 at each eccentricity) with no flankers. The experimental trials were preceded by 18 practice trials, and they were presented randomly for each participant, in four blocks of 144 trials each.

Results

The dependent measure of interest in the current study was participants' categorization accuracy. We conducted a series of distinct analyses to determine the extent to which different kinds of flankers led to varying amounts of visual crowding. First, we chose to analyze the data obtained from foveally-presented trials separately from the data obtained from peripherally-presented trials. Second, in each of these analyses, we used difference scores to quantify the

effect of each flanker type on performance relative to the no-flankers condition. Specifically, we subtracted each participant's accuracy in the no-flankers condition from their performance in each of the conditions in which flankers were present, yielding a value that reflected the performance cost incurred by including flankers of each type. We analyzed these values using a 2x2x2 mixed-design ANOVA with flanker orientation (upright vs. inverted) and flanker type (face vs. character) as within-subjects factors and participant group (character expert vs. novice) as a between-subjects factor. These analyses allowed us to examine how the cost of flankers on peripheral target categorization varied according to stimulus factors and expertise. Finally, we used single-sample t-tests to determine whether the cost of each type of flanker was significant larger than zero. We included this analysis because we are not solely interested in how crowding varies with flanker type, but also in whether some flankers do not cause measurable crowding across participants. We carried out this analysis solely with our data from peripherally-presented trials. Average raw performance in each condition is displayed in Figure 2 below.

Figure 2. The mean percentage of correct responses in different experimental conditions for (A) native Chinese and (B) non-Chinese readers in Experiment 1. Error bars represent standard errors of the means. (CC: Chinese character)

Foveal-presentation analyses

Our analysis of the difference scores obtained from trials presented in central vision yielded a significant main effect of flanker type ($F(1,37)=5.25$, $p=0.028$), but no other significant main effects ($F<1$ in each case). This effect appears to be driven by significantly more positive values from face flankers than character flankers, but we note that in all conditions the average difference score is close to zero. The interaction between flanker type and participant group was marginally significant ($F(1,37)=3.61$, $p=0.065$), but we did not choose to follow up on this interaction via post-hoc tests given both the low difference-score values observed in all conditions and the absence of any *a priori* hypothesis regarding the impact of flankers on target categorization in central vision.

Peripheral-presentation analyses

Our analysis of the difference scores obtained from trials presented in peripheral vision yielded a significant main effect of flanker type ($F(1,37)=100.97$, $p<0.001$), resulting from more negative difference score values in the face flanker conditions than in the character flankers conditions (Figure 3). Neither the main effect of flanker orientation ($F(1,37)=1.78$, $p=0.19$) nor the main effect of participant group ($F(1,37)=0.10$, $p=0.75$) reached significance. We did, however, observe a significant interaction between flanker orientation and participant group ($F(1,37)=5.83$, $p=0.021$), such that flanker orientation affected performance in Chinese-character experts, but not novices.

Figure 3. Average accuracy cost for the presence of each flanker type in peripheral vision across participants. These scores were calculated by subtracting performance in the “No flankers” condition from performance in each of the conditions in which flankers were present. Negative values thus reflect poorer performance when flankers were present, which is consistent with the phenomenology of visual crowding. Error bars represent 95% credible intervals (JASP, 2018).

Finally, our comparison of difference scores to zero-cost in each condition yielded significant outcomes for upright and inverted face flankers in both participant groups (see Table 1). Character flankers (post-Bonferroni correction) did not yield significantly non-zero values in any orientation for either group.

	Chinese Experts	Non-Experts
Upright Faces	$t(18)=6.86, p<0.001$	$t(19)=7.23, p<0.001$
Inverted Faces	$t(18)=5.54, p<0.001$	$t(19)=7.64, p<0.001$
Upright Characters	$t(18)=1.48, p=0.079$	$t(19)=-0.25, p=0.50$
Inverted Characters	$t(18)=-0.42, p=0.66$	$t(19)=-0.041, p=0.52$

Table 1 – Single-sample t-tests of difference scores for peripherally-viewed arrays in Experiment 1 against zero. This comparison reveals whether the presence of flankers in each condition led to significantly poorer performance than in their absence.

Discussion

Experiment 1 showed that participants' categorization performance was worse when the target face was surrounded by face compared to Chinese character flankers, demonstrating the effect of target-flanker similarity on crowding. More importantly, the results of Experiment 1 showed that the crowding effect of Chinese character flankers on target categorization was weakly modulated by Chinese-reading expertise. Native Chinese readers, but not non-Chinese readers, showed a stronger crowding effect when a target face was flanked by upright compared to inverted Chinese characters. We also found that face flanker inversion reduced crowding in native Chinese readers, but not in non-Chinese readers, contradicting our prediction that both groups of participants should experience stronger crowding when a target face was flanked by upright compared to inverted faces. Therefore, in Experiment 2, we examined the flanker inversion effect on crowding more carefully using a new set of face stimuli.

Experiment 2

The results of Experiment 1 showed that native Chinese readers experienced more crowding when target faces were flanked by upright compared to inverted faces or Chinese characters, suggesting that higher-level object representations play an influential role in modulating the crowding effect. In contrast, non-Chinese readers' categorization performance was not affected by the orientation of Chinese character flankers, presumably due to the lack of Chinese-reading expertise. However, when target faces were flanked by other familiar stimuli, such as faces, the flanker inversion effect was still absent in our non-Chinese readers. This finding implies that the observed crowding effect could mainly be driven by interference between lower-level facial features [e.g., the eyes, nose, mouth, which are not sensitive to inversion according to McKone and Yovel (2009)], rather than high-level face representations, of the target and flankers. Consequently, upright and inverted face flankers may have resulted in similar crowding effects on the recognition of target faces.

To further test this possibility, in Experiment 2, we replicated the design of Experiment 1 but replaced the grayscale face stimuli with two-tone black and white Mooney faces, which lack clear facial features and are difficult to recognize as faces when inverted. In order to perceive the black and white image as a face, the image must be processed holistically (e.g., Farzin et al., 2009). We expected to observe a stronger crowding effect when target faces were surrounded by upright compared to inverted face flankers for both reader groups. We also expected that upright Chinese character flankers would elicit more crowding than inverted Chinese character flankers, but only for the native Chinese reader group.

Methods

Participants

Eighteen native Chinese readers (9 males, 9 females) and 21 non-Chinese readers (10 males, 11 females) at North Dakota State University participated in the study for course credit or monetary compensation. The mean ages of native Chinese and non-Chinese readers were 22.1 and 19.1 years, respectively. All native Chinese readers were originally from Taiwan, mainland China, or Malaysia, and all non-Chinese readers were Caucasians. They all had normal or correct-to-normal vision. All participants were naïve to the purpose of the study, and none had participated in the previous experiment. The North Dakota State University Institutional Review Board approved the study, and all participants gave informed consent.

Apparatus, stimuli, procedure, and design

Experiment 2 was identical to Experiment 1, except that 22 Mooney faces were used to replace the grayscale faces, and all stimuli were presented on a black background. To make the Mooney faces, we used Adobe Photoshop CS5 to apply Gaussian blurring and intensity thresholds to 22 front-view Caucasian faces (11 males, 11 females) with neutral expressions chosen from the grayscale FERET database. Figure 4 shows the sequence of events in each trial as well as sample stimuli for different experimental conditions.

Figure 4. Left: The sequence of events within a trial in which the target face appeared to the left of the fixation in Experiment 2. Right: Example stimuli for different combinations of flanker type (face, Chinese character) and orientation (upright, inverted). All images depict trials in which a target face and its flankers appeared to the left of the fixation.

Results

We analyzed the data from Experiment 2 using the same strategy as described previously in Experiment 1. Briefly, we calculated difference scores for each flanker type in central and peripheral vision, and analyzed these using a 2x2x2 mixed-design ANOVA with flanker type and flanker orientation as within-subject factors, and participant group as a between-subjects factor. We further analyzed the data from peripherally-presented trials using single-sample t-tests to determine if each flanker condition incurred a performance cost that was significantly more negative than zero. Average raw performance in each condition is displayed in Figure 5 below.

(A)

(B)

Figure 5. The mean percentage of correct responses in different experimental conditions for (A) native Chinese and (B) non-Chinese readers in Experiment 2. Error bars represent standard errors of the means. (CC: Chinese character)

Foveal-presentation analyses

In central vision, we observed no significant main effects nor any significant interactions between factors. Neither stimulus factors nor participant experience with Chinese characters appears to affect target categorization in central vision.

Peripheral-presentation analyses

In peripheral vision, we observed significant main effects of flanker type ($F(1,37)=12.6$, $p<0.001$) such that face flankers yielded more negative difference scores (a larger performance cost) than character flankers (Figure 6). We also observed a main effect of flanker orientation ($F(1,37)=12.19$, $p<0.001$) such that upright flankers yielded more negative difference scores than inverted flankers. The main effect of group ($F(1,37)=0.64$, $p=0.43$) did not reach significance. However, we also observed a significant interaction between flanker orientation and participant group ($F(1,37)=17.22$, $p<0.001$) such that the effect of flanker orientation was evident in Chinese-character experts, but not in novices. We also observed marginally significant interactions between flanker type and participant group ($F(1,37)=3.81$, $p=0.058$), flanker orientation and flanker type ($F(1,37)=3.57$, $p=0.067$), and between flanker orientation, flanker type, and participant group ($F(1,37)=3.26$, $p=0.079$). Rather than try to elaborate on all of these marginal interactions, we continue by describing the outcome of our single-sample tests comparing the difference score in each condition to chance.

Figure 6. Average accuracy cost for the presence of each flanker type in peripheral vision across participants in Experiment 2. These scores were calculated by subtracting performance in the “No flankers” condition from performance in each of the conditions in which flankers were present. Negative values thus reflect poorer performance when flankers were present, which is consistent with the phenomenology of visual crowding. Error bars represent 95% credible intervals (JASP, 2018).

Our comparisons of difference-score values to a cost of zero in each condition yielded an intriguing pattern of results (Table 2). Upright face flankers led to a significant decrement in performance in both participant groups, but inverted face flankers only significantly lowered performance in the novice group. Upright Chinese characters marginally lowered performance in Chinese-character experts (Our critical alpha value after Bonferroni correction is 0.00625), but did not significantly affect performance in the novice group. Finally, inverted Chinese characters did not affect performance in either group.

	Chinese Experts	Non-Experts
Upright Faces	$t(17)=3.78, p<0.001$	$t(20)=2.52, p=0.01$
Inverted Faces	$t(17)=-1.71, p<0.95$	$t(20)=3.65, p<0.001$
Upright Characters	$t(17)=2.67, p=0.008$	$t(20)=0.12, p=0.55$
Inverted Characters	$t(17)=-0.36, p=0.64$	$t(20)=0.40, p=0.35$

Table 2 – Single-sample t-tests of difference scores for peripherally-viewed arrays in Experiment 2 against zero. This comparison reveals whether the presence of flankers in each condition led to significantly poorer performance than in their absence.

Discussion

Consistent with Experiment 1, the results of Experiment 2 showed stronger crowding when a target face was surrounded by faces compared to Chinese characters, demonstrating the influence of target-flanker similarity on target recognition in a crowded display. Additionally, native Chinese readers showed stronger crowding when a peripheral target face was surrounded by upright compare to inverted faces or Chinese characters, suggesting that higher-level object representations play an influential role in modulating visual crowding. However, the results of Experiment 2 showed no inversion effect with either face or Chinese character flankers in non-Chinese readers, contrary to our prediction that non-Chinese readers' categorization performance should be affected by the orientation of face flankers. Upright and inverted face flankers caused the same amount of crowding in non-Chinese readers, despite the fact that we used a new set of face stimuli which have no distinct facial features and are difficult to be perceived as faces when inverted.

General Discussion

In two experiments, we examined how visual expertise affects crowding. We had native Chinese and non-Chinese readers categorize target faces surrounded by face or Chinese character flankers that were presented either upright or inverted. Our results showed that a peripheral target face was more difficult to recognize when presented with faces compared to Chinese characters, consistent with studies showing stronger crowding when target and flankers are similar in stimulus properties, such as shape (Kooi et al., 1994), spatial frequency (Chung, Levi, & Legge, 2001), color (Kooi et al., 1994; Pöder, 2007), visual complexity (Bernard & Chung, 2011; Chanceaux, Mathôt, & Grainger, 2014), and categorical membership (Huckauf, Heller, & Nazir, 1999; Reuther & Chakravarthi, 2014; Sun & Balas, 2015). Note that the modulation of crowding with target-flanker similarity could be due to interference between low-level feature properties as well as higher-level object representations. For example, when a target letter and its flankers share more similar basic visual features, more errors occur during the subsequent combinations between target and flanker features within the integration field (the feature integration hypothesis, Pelli et al., 2004), thus increasing the error rate of target letter identification (Bernard & Chung, 2011). However, when visual feature similarity is kept constant, assigning different categorical meanings to the target and flankers also modulates crowding, with same-category objects more likely to crowd each other (Reuther & Chakravarthi, 2014). Additionally, schematic face flankers bore essentially no resemblance to the facial features in the target faces can cause significant crowding as well (Sun & Balas, 2015).

We also manipulated flanker orientation to further examine how higher-level object representations and low-level visual features affect crowding. Research has demonstrated that

configural information can be important for processing Chinese characters (e.g., Chen et al., 2013; Wong et al., 2012); inversion disrupts configural processing and causes impaired Chinese character recognition (Kao et al., 2010). Consequently, the intact global representations of the upright Chinese characters should induce a larger crowding effect on target face categorization compared to the inverted ones in native Chinese readers (though see Cheung & Cheung, 2017 for data suggesting that target-flanker similarity does not affect crowding strength in all cases). On the contrary, for non-Chinese readers, unfamiliar Chinese characters are meaningless objects when presented either upright or inverted, and thus should cause no difference in crowding. Our results support this hypothesis. We found that native Chinese readers consistently showed poor performance when target faces were surrounded by upright compared to inverted Chinese characters, whereas non-Chinese readers showed no such flanker inversion effect. This finding confirms that perceptual experience plays an influential role in modulating crowding.

The inversion effect of Chinese character flankers on face categorization also implies that crowding occurs between higher-level object representations. Studies using simple stimuli (e.g., line segments, letters) have suggested that crowding originates at an early stage of visual processing, such as where the binding of low-level visual features occurs (Parkes et al., 2001; Pelli et al., 2004; Tripathy & Cavanagh, 2002). However, if interference among low-level features is the only source for crowding, then upright and inverted Chinese characters should cause a similar amount of crowding given that inversion disrupts the processing of configural object representations but not the processing of low-level visual features (e.g., luminance, color, texture, spatial frequency). Our results showed that this is not the case. Native Chinese readers showed more crowding when target faces were surrounded by upright compared to inverted Chinese characters, suggesting that crowding occurs at a later stage of visual processing, such as

where higher-level object representations are formed. The results are also consistent with recent research showing that crowding can occur at different levels of visual processing (e.g., Anderson, Dakin, Schwarzkopf, Rees, & Greenwood, 2012; Ikeda, Watanabe, & Cavanagh, 2013; Whitney, 2009; Whitney & Levi, 2011).

Interestingly, we also found that orientation of face flankers affected crowding in native Chinese readers, but not in non-Chinese readers. Our results differ from those showing more crowding when target faces are flanked by upright compared to inverted faces using Caucasian participants (Farzin et al., 2009; Louie et al., 2007). Broadly speaking, this discrepancy may be due to a range of factors, such as different stimulus properties (e.g., larger face stimuli, greater target-flanker spacing) and task designs (e.g., shorter stimulus presentation time, less number of trials) in our experiments (see also Sun and Balas, 2015). The absence of the flanker inversion effect in non-Chinese readers does not necessarily mean that faces are not processed configurally by these participants, but rather that some aspects of our stimuli made this effect difficult to measure. We note that in related work (Sun & Balas, 2015) we have also reported the absence of this interaction using a similar paradigm, which suggests that the effect of stimulus orientation on face crowding may simply be susceptible to changes in task demands and stimulus appearance. Indeed, Kalpadakis-Smith, Goffaux & Greenwood (2018) demonstrated convincingly that task difficulty can obscure the effects of target-flanker similarity on crowding. In the current study, it is thus possible that our use of a gender categorization task (as opposed to an identity matching task or an eye-spacing judgment) could have raised overall task difficulty sufficiently to make it difficult to observe such effects.

However, this explanation does not clarify why crowding *was* modulated by face flankers' orientation in our native Chinese readers. What perceptual or cognitive factors might contribute

to this group effect observed in both experiments? We can only speculate given the current data, but one interesting possibility is that this discrepancy may be related to participants' distinct perceptual processing styles, as East Asians (in some contexts) tend to process visual information in a more holistic way and are therefore more susceptible to contextual influences compared to Westerners (for reviews, see Nisbett & Masuda, 2003; Nisbett & Miyamoto, 2005; Nisbett, Peng, Choi, & Norenzayan, 2001). For example, Masuda and Nisbett (2001) had American and Japanese participants view pictures containing an animal against a scene background (e.g., a wolf in the forest) and make old/new judgments for these animals in a new series of pictures. Compared to Americans, Japanese showed worse performance when the animal was presented in a novel background (e.g., a wolf in the desert). The results suggest that Japanese encode the picture content more holistically than Americans do, and they tend to bind the target object with the background. Consequently, their performance is more likely to be affected by background changes. In Kitayama, Duffy, Kawamura, and Larsen (2003), American and Japanese participants viewed a line presented within a square frame, followed by another square frame of the same or different size. Participants had to draw a line that was either of the exact same length as the previous line (absolute task) or proportional to the height of the current testing frame (relative task). The results showed that Americans were more accurate in the absolute task, whereas Japanese were more accurate in the relative task, suggesting that individuals from Eastern cultures are more affected by the surrounding context while making a judgment on a focal object. Therefore, it is possible that in our study, native Chinese readers engaged in a more holistic perceptual process in comparison to non-Chinese readers. Their sensitivity to contextual information, such as flanker orientation, thus affects the strength of crowding when face or Chinese character flankers are presented upright or inverted. However, further experiments are

required to test this interpretation and examine to what degree this effect is due to visual expertise or culture difference (e.g., whether the flanker inversion effect could be obtained with other daily objects in native Chinese readers). Regardless, the current study provides evidence that properties of visual crowding are affected by experience. Even though we cannot make a strong case for holistic processing as the key contributing factor to the observed difference between groups, our results point to an intriguing effect of visual experience on crowding. Whether or not holistic processing itself is ultimately the best account of these data, our main contribution is the demonstration that properties of crowding vary as a function of visual experience, whether that is a reflection of visual expertise and its sequelae or culture.

To conclude, the current study tested how visual expertise affects crowding and showed that crowding is susceptible to both low- and high-level visual information. We found that perceptual expertise with the flanking stimuli plays an influential role in modulating crowding. Additionally, distinct perceptual processing styles shaped by cultures also affect the strength of crowding. Our results are therefore consistent with recent research suggesting that crowding cannot be explained by purely low-level feature interactions (e.g., Herzog & Manassi, 2015; Reuther & Chakravarthi, 2014; Sun & Balas, 2015).

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