Not all visual expertise is holistic, but it may be leftist: The case of Chinese character recognition

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ABSTRACT

We use the logographic characteristic of Chinese orthography to examine whether face-specific effects, such as holistic processing and the left side bias effect, can also be observed in expertise-level Chinese character processing by comparing novices' and experts' perception of Chinese characters. We show that non-Chinese readers (novices) perceive characters more holistically than Chinese readers (experts). Chinese readers have a better awareness of the components of characters, which are not clearly separable to novices. This suggests that holistic processing is not a general visual expertise marker; it depends on the features of the stimuli and the tasks typically performed on them. In contrast, similar to face perception, Chinese readers have a left side bias effect in the perception of mirror-symmetric characters, whereas novices do not; this effect is also reflected in their eye fixation behavior. This suggests that the left side bias effect may be a visual expertise marker.

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Introduction

Faces are a type of visual stimuli that we have extensive exposure to since birth. As a result, we are all experts in face recognition. Several behavioral expertise markers in face processing have been identified, such as holistic processing, although it remains controversial whether these effects are expertise markers that apply to both faces and objects (e.g., Bukach, Gauthier, & Tarr, 2006) or specific to face expertise (e.g., McKone, Kanwisher, & Duchaine, 2007; Robbins & McKone, 2007). Similar to faces, words are another type of stimuli that we have a biased exposure to since our childhood, although slightly later than faces. Nevertheless, it remains unclear whether the face expertise markers also exist in visual word processing. Unlike faces, words in alphabetic languages such as English do not have a homogeneous configuration, and word processing relies on identifying the serial order of a restricted set of letters in different lengths (Wong & Gauthier, 2006). These differences make a direct comparison between face and English word processing difficult.

In contrast, Chinese orthography is a logographic writing system, in which graphemes represent words, as opposed to a serial order of letters in alphabetic languages. Characters can be regarded as the perceptual units of the orthography. They consist of individual strokes; several strokes together compose individual stroke patterns, which are the recurrent constituent units of characters. The stroke patterns stack in several different formats to form a character (Figure 1). There are more than a thousand stroke patterns in Chinese orthography (Hsiao & Shillcock, 2006), and each stroke pattern does not usually correspond to a certain phoneme, unlike letters in English words. To recognize characters, Chinese readers have to identify the constituent stroke patterns in a character, which may look like an integral whole to non-Chinese readers. It has been shown that these stroke patterns are indeed the smallest functional units in Chinese character recognition (Chen, Allport, & Marshall, 2000).

Chinese characters share many properties with faces (McCleery et al., 2008). Like faces, they must be recognized at the individual level; other research on expertise effects in Chinese characters has shown speedups at the individual character level compared to the font or superordinate level, suggesting the individual character is the entry level in experts (Wong & Gauthier, 2006)[1]. Literate Chinese must know 3,000 to 4,000 of them. They have a homogenous shape (square), and a canonical, upright orientation. Some characters have a mirror-symmetric configuration as faces. For Chinese readers, they are highly learned, and must be recognized regardless of fonts (like expressions in faces). Featural information is also critical for character recognition. However, there are also some differences between face and character recognition. For example, configural information, which has been shown to be important for face processing, is not important for character recognition (Ge et al., 2006); Chinese readers have to pay attention to the relationship among stroke patterns while deemphasizing the exact spacing among them in order to efficiently recognize characters. In addition, unlike face processing, in which every adult has ample experience, a direct comparison between adult experts and novices is possible through comparing native readers and non-readers. Such examinations will enable us to identify expertise markers. Here we examine two face expertise effects, holistic processing and left side bias, and determine whether they also exist in Chinese character expertise.

Holistic Processing

We use the complete composite paradigm to examine holistic processing effects (Gauthier & Bukach, 2007). In the composite paradigm, participants are presented with two stimuli briefly, either sequentially or simultaneously. They are told to attend to either the top or bottom halves of the stimuli, and judge whether they are the same or different. In congruent trials, the attended and irrelevant halves lead to the same response (i.e., both are the same or different). In incongruent trials, the attended and irrelevant halves lead to different responses. Holistic processing is indicated by the interference from the irrelevant halves in the matching of the attended halves; it can be assessed by the performance difference between the congruent and the incongruent trials (i.e., a congruency effect; Figure 2a).[2] If holistic processing is an expertise marker, the effect should be observed among experts but not novices.

Methods

Materials

The materials consisted of 80 pairs of Chinese characters that have a top-bottom configuration (Figure 1, middle), with 20 pairs in each of the four conditions in Figure 2a. Each character can be horizontally divided into two components; they were selected carefully so that each pair of components to be attended/compared would appear in one congruent and one incongruent trial (Figure 2a shows an example). All characters were within a medium to high frequency range (Huang, 1995). There was no significant frequency difference between the characters used in the congruent and incongruent trials (t-test). Characters were presented in Ming font (Figure 2a).

Participants

We recruited eight male and eight female native Chinese readers from Taiwan (i.e., international students) as experts, and eight male and eight female participants who do not have any experience in any Asian languages as novices for the study. They are all UCSD students (mean age 25 years 3 months); all right handed according to the Edinburgh handedness inventory (Oldfield, 1971); all have normal or corrected to normal vision. They participated for course credit or received a small honorarium for their participation.

Design

The design had a within-subject variable: congruency (congruent vs. incongruent), and a between-subject variable: expertise (expert vs. novice). The dependent variable was discrimination performance measured by A', a bias-free nonparametric measure of sensitivity. The value of A' varies between 0.5 to 1.0; higher A' indicates better discrimination. Unlike d', A' can be computed when cells with zero responses are present[3].

Procedure

In each trial, after the 1000 ms central fixation, participants were cued with a symbol indicating which half (top or bottom) they should attend to and performed a same-different judgment (Figure 2b); the two characters were presented above and below the initial fixation respectively, about five degrees of visual angle away from each other. Each character subtended about 1.5 degrees of visual angle. Participants were told to look at each character once during the 600 ms presentation time (cf. Robbins & McKone, 2007), and respond as quickly and accurately as possible by pressing the corresponding buttons. They performed a practice session with characters not in the materials before the experiment.

Results

The results showed a congruency effect among the novices ($F(1, 15) = 10.667$, $P = 0.005$, $p_{rep} = 0.966$, $\eta_p^2 = 0.416$) but not the experts; the interaction between expertise and congruency was significant ($F(1, 30) = 4.774$, $p < 0.05$, $p_{rep} = 0.897$, $\eta_p^2 = 0.137$; Figure 3). This shows that novices perceive characters more holistically than experts, and suggests that holistic processing is not an expertise marker. Chinese readers have a better awareness of character components compared with non-Chinese readers; thus it is easier for them to attend to specific parts of characters, whereas non-Chinese readers may have difficulty separating the components and tend to group them according to similarity or continuality of features.

Our results could be a ceiling effect, since the experts have a very high A' (average = 0.978). In order to eliminate this possibility, we conducted a follow-up experiment, aiming at bringing the experts' performance down to a similar level to the novices' performance in the first experiment. We made the task harder by reducing the contrast level of the stimuli and shortening the presentation time to 500 ms. We also split the characters with a red horizontal line (Figure 4) to match previous experiments with faces and objects (e.g. Robbins & McKone, 2007). In addition, we included misaligned and inverted character conditions (Figure 5): if the holistic processing effect in novices is indeed due to the interference from the irrelevant halves, the effect should be reduced by misalignment; if the absence of the holistic processing effect in experts is indeed due to their expertise, with inverted characters experts should become like novices and process them holistically[4].

The results with upright characters again showed a significant interaction between expertise and congruency ($F(1, 28) = 4.602$, $p < 0.05$, $p_{rep} = 0.891$, $\eta_p^2 = 0.141$; Figure 5): the congruency effect was evident among the novices ($F(1, 14) = 12.526$, $P = 0.003$, $p_{rep} = 0.974$, $\eta_p^2 = 0.472$) but not the experts, even though the experts' performance decreased to a similar level to the novices' performance in the first experiment (i.e., average A' decreased from 0.978 to 0.948; 0.95 in A' is about 90% in accuracy; the novices had a larger drop: from 0.940 to 0.875 in A'). This result suggests that the absence of a congruency effect among the experts in the first experiment is unlikely to be simply due to a ceiling effect.

The results also showed that misalignment significantly reduced the congruency effect among the novices: a significant interaction between congruency and misalignment (aligned vs. misaligned) ($F(1, 14) = 4.909$, $P < 0.05$, $p_{rep} = 0.886$, $\eta_p^2 = 0.260$); there was no misalignment effect among the experts (Figure 6). In contrast, inversion led to a congruency effect among the experts: a significant interaction between congruency and inversion (upright vs. inverted) ($F(1, 14) = 5.517$, $P < 0.05$, $p_{rep} = 0.902$, $\eta_p^2 = 0.283$); there was no inversion effect among the novices (Figure 7). These results confirm that the congruency effect is due to the inability to selectively attend to character parts.

Left Side Bias

In face perception, a left side bias effect has been consistently reported: a chimeric face made from two left half faces from the viewer's perspective is usually judged more similar to the original face than that made from two right half faces (Gilbert & Bakan, 1973; Brady, Campbell, & Flaherty, 2005; Figure 8a). This phenomenon has been argued to be an indicator of right hemisphere (RH) involvement in face perception (Burt & Perrett, 1997). Studies examining eye movements in face processing also showed a preference to look at the left side of the gaze field (e.g., Mertens, Siegmund, & Grusser, 1993; Hsiao & Cottrell, *in press*; Butler et al., 2005; Everdell et al., 2007) and an initial saccade bias, mostly to the left (Leonards & Scott-Samuel, 2005) for viewing faces but not for other objects. These effects have never been observed in the perception of other types of objects.

Here we examine whether this effect can also be observed in Chinese character perception. The materials consist of mirror-symmetric characters in the most common fonts (Ming and Kai). Similar to faces, these characters are symmetric in configuration, but have some asymmetric features due to shapes of strokes. We thus are able to create chimeric characters in the same fashion as chimeric faces (Figure 8b). We present these chimeric characters to both Chinese and non-Chinese readers and ask them to judge whether the left or right chimeric character looks more similar to the original one (Figure 8c).

Materials

The materials consisted of 30 Chinese mirror-symmetric characters (Figure 1, right); all were high frequency characters according to Huang (1995). Each character was presented twice in Ming and Kai fonts respectively; in total there were 60 trials. To counterbalance possible differences between the two sides of the characters, in half of the trials the mirror image of the original stimulus was presented; if a character was presented in Ming font in its original form, the same character in Kai font would be presented in its mirror-image; for each stimulus, the presentation of the original/mirror-image forms was counterbalanced across participants.

Participants

We recruited 14 male and 14 female native Chinese readers from Taiwan as experts, and another 14 male and 14 female participants who do not have any experience in any Asian languages as novices. They are all UCSD students (mean age 25 years 4 months); all right handed according to the Edinburgh handedness inventory (Oldfield, 1971); all have normal or corrected to normal vision. They participated for course credit or received a small honorarium for their participation.

Design

The design had a between-subject variable: expertise (expert vs. novice). The dependent variable was the left chimeric character preference, defined as the number of trials the left chimeric character was judged more similar to the original character divided by the total number of trials.

Procedure

In each trial the original character was presented next to either the left or right side of the screen, counterbalanced among participants (cf. Brady et al., 2005; Figure 8c). Participants were told to follow the arrow at the center to look at the original character first; at the same time the two chimeric characters were presented above and below the arrow respectively, each was about 2.5 degrees of visual angle away from the center. Each character subtended about 1.5 degrees of visual angle. Participants were told to judge which of the two characters looked more similar to the one on the side by pressing the corresponding buttons. The characters stayed on the screen until the response.

Results

The results showed a strong expertise effect ($F(1, 56) = 14.896$, $p < 0.001$, $p_{rep} = 0.992$, $\eta_p^2 = 0.216$): the experts had a significant left chimeric character preference (56.7%; $F(1, 27) = 15.489$, $p = 0.001$, $p_{rep} = 0.986$, $\eta_p^2 = 0.365$), whereas the novices did not have a preference (48.3%; *n.s.*; Figure 9). This result thus supports the expertise account for the left side bias effect in face perception and suggests the RH involvement in Chinese character expertise.

Previous studies showed the left side bias effect in face perception is also reflected in eye movements (e.g., Butler et al., 2005). Thus, during the experiment we recorded eye movements from 12 novices and 12 experts (half males and half females)[5] and analyzed the fixations made onto the characters with a linear mixed model; the fixed factors were expertise (expert vs. novice) and character location (left, right, top, and bottom; Figure 8c), and the random factors were subject and image identities. The results showed a strong expertise effect in fixation location in the x-direction ($F(1, 1354.818) = 11.554$, $p = 0.001$, $p_{rep} = 0.986$): the experts' fixations were more to the left than the novices' (Figure 10). On average, the experts' fixations shifted leftward from the center about 5.6% of the whole character in pixels ($F(1, 6152.939) = 12.735$, $p < 0.001$, $p_{rep} = 0.992$), whereas the novices' fixations were only shifted about 1.5%[6]. This result again suggests that the left side bias effect is related to visual expertise.

Discussion

Here we examined whether holistic processing and the left side bias effect in face processing can also be observed in expertise-level Chinese character processing. We show that novices process Chinese characters more holistically than experts; this result suggests that holistic processing is not an expertise marker. Hence, whether holistic processing is employed depends on the stimulus features and the task typically performed on the stimuli. Chinese characters consist of features that are not clearly separable to novices; what Chinese readers have been trained for is the ability to separate and group individual features into discernible components (Chen et al., 1996) and ignore some configural information (e.g., relative distances between features; Ge et al., 2006). Chinese characters thus provide us with a unique opportunity to show this effect. This effect may be less clear in alphabetic languages such as English, since the separation of letters is already discernable to novices.

We also show that misalignment of character halves significantly reduces holistic processing in novices; this phenomenon is consistent with the holistic processing effect in the face recognition literature in experts. This confirms that holistic processing in novices is due to the inability to selectively attend to character parts; when the parts are misaligned, the effect is reduced since the interference from the irrelevant parts is reduced. In addition, we show that inversion of characters leads to holistic processing in experts; this phenomenon is also consistent with the face/object recognition literature, showing that expert processing is tuned by experience. For example, it has been shown that the congruency effect is stronger for own-race compared with other-race faces (Michel et al., 2006). In our study, experts may have difficulty isolating and detecting constituent stroke patterns in the inverted characters; hence, the holistic processing effect emerges. These results show that the expertise in Chinese character recognition develops a skill that is opposite to the recognition of faces: to perceive the stimuli less holistically. In other words, holistic processing is not an expertise marker; it depends on the stimulus features and the task typically performed on the stimuli.

As future directions, similar to face recognition, the reduced holistic processing in experts of Chinese character recognition may be influenced by familiarity (e.g., Harris and Aguirre, 2008). For example, the holistic processing effect may re-emerge in experts with low-frequency characters or pseudo-characters (by analogy with unfamiliar faces) compared with high-frequency characters. In contrast, if the reduced holistic processing is because of experts' familiarity with the constituent stroke patterns, the effect may be influenced by stroke pattern frequency rather than character frequency. These issues require further examination.

In the examination of the left side bias effect in Chinese character perception, we showed that experts have a significantly stronger left chimeric character preference than novices. Thus, the left side bias effect in face perception is not face-specific; it is an expertise marker for Chinese character processing. This also suggests a RH involvement in Chinese character expertise, and is consistent with the left visual field/RH advantage observed in Chinese orthographic processing (e.g., Tzeng et al., 1979; Yang & Cheng, 1999). The processing of the RH has been argued to be more coarsely-tuned than the left hemisphere (LH) (e.g. Jung-Beeman, 2005). Studies examining neural microcircuitry suggest that the cortical columns in the RH are in general more densely interconnected than those in the LH, suggesting a more functionally overlapped representation in the RH compared with the LH (e.g. Hutsler & Galuske, 2003). Behavioral data also suggest that the RH has an advantage over the LH in tasks requiring processing of low frequency information (e.g. Ivry & Robertson, 1998). The current results thus may suggest more efficient processing by extracting and integrating information from the more functionally overlapped and/or low frequency biased representation in the RH after the expertise is acquired.

Faces and Chinese characters have several fundamental differences in their features, configurations, and the tasks typically performed on them. The left side bias effect is nevertheless observed in both expertise-level character and face perception; this phenomenon suggests that it may be a general visual expertise marker. This hypothesis is consistent with human fMRI studies of object processing showing that discrimination/expertise training effect is stronger in the RH compared with the LH (e.g., Op de Beeck et al., 2006; Gauthier et al., 1999). One exception is the classical right visual field/LH advantage in reading English words (e.g., Bryden & Rainey, 1963). Maurer and McCandliss (2007) proposed the phonological mapping hypothesis which argues that the LH lateralization for word processing in alphabetic languages may be specifically related to the influence of grapheme-phoneme conversion established during learning to read. Further examination is required to understand under what conditions visual processing will rely more on the LH than the RH representation.

We also show that this left side bias effect in Chinese character perception is reflected in eye movements: experts' fixations on the characters shift leftwards compared with novices' fixations. This leftward bias in eye fixation has also been observed in face recognition and argued to be related to the RH involvement in face processing (e.g., Hsiao & Cottrell, *in press*). The current results suggest a link between RH processing and visual expertise. Because of the contralateral projection from the visual hemifields to the hemispheres, the left half of the stimuli may have been constantly encoded and processed in the RH during learning (Hsiao, Shieh, & Cottrell, *in press*). Consequently, experts direct their fixations more to the left, compared with novices, since the internal representation of the left stimulus-half is more informative and hence attracts their attention.

In conclusion, the current study suggests that the controversy about whether face processing is unique or due to expertise may partly be due to the confusion about what the real expertise markers are. In Chinese character perception, holistic processing, assessed by the congruency effect in a composite paradigm, is stronger among novices compared with experts, suggesting that holistic processing is stimulus- and task-dependent; it is not an expertise marker. In contrast, the left side bias effect observed in both face and expertise-level Chinese character processing, but not for novices, suggests that it may be a more general visual expertise marker. Thus, the visual expertise effects may be decomposed into at least two components: a common component that involves an efficient coarse-coding developed in the RH, and a stimulus-dependent component. In face processing, it may be feature grouping that results in holistic processing, due to a homogeneous configuration among faces. In Chinese character processing, it may be the component isolation and identification acquired during learning, which leads to reduced holistic processing in experts.

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Footnotes

[1] What the basic level of word recognition is remains controversial. Rosch (1978) proposed that the basic level of categorization is determined by the level at which objects show the most increase in shape similarity. Wong and Gauthier (2006) thus define individual letters as structural basic-level categories (e.g., letter "K" category) since different letters do not share structural parts. In Chinese character recognition, characters with a specific structure (e.g., top-bottom structure; Figure 1) can be considered as a basic-level category.

[2] This design avoids response bias effects that can lead to incorrect conclusions in the partial composite design in which the irrelevant halves are always different (Robbins & McKone, 2007).

[3] $A' = 0.5 + \left[sign(H - F)\dfrac{(H-F)^2 + |H-F|}{4\max(H,F) - 4HF} \right]$, where H and F are the hit rate and false alarm rate respectively. The d' measure may be affected by response bias when assumptions of normality and equal standard deviations are not met (Stanislaw & Todorov, 1999). In our study, novices had a bias towards "same" responses ($p = 0.07$ in the first experiment; $p < 0.01$ for all conditions in the follow-up experiment); experts had this bias only with inverted characters ($p = 0.02$).

[4] We recruited seven male and eight female experts, and seven male and eight female novices; all UCSD students (mean age 24 years 7 months), right handed, and with normal or corrected to normal vision. The same design and procedure was used. Each participant performed three experiment blocks: upright, misaligned, and inverted; the block order was counterbalanced across participants.

[5] An EyeLink II eye tracker was used; the data of the eye with less calibration error were used for analysis. The tracking mode was pupil only with a sample rate 500 Hz; the resolution was 0.01 degree of visual angle. A chinrest was used to reduce head movements. In data acquisition, saccade motion threshold was 0.1 degree of visual angle; saccade acceleration threshold was 8000 degree/square second; saccade velocity threshold was 30 degree/second (EyeLink II defaults for cognitive research). The standard nine-point calibration procedure was administered in the beginning and repeated whenever the drift correction error was larger than one degree of visual angle. Drift correction was performed in the beginning of every trial.

[6] The novices' fixations were also very slightly away from the center ($p = 0.018$). This may reflect the 'pseudoneglect' effect: right-handed subjects systematically tend to bisect lines left of the center (Bowers & Heilman, 1980); this effect has often been linked to stronger activation of the RH in response to the visuospatial nature of the task (Vingiano, 1991).

Figure 1. Examples of Chinese characters: Left-right, top-bottom, and mirror-symmetric.

Figure 2. (a) The complete composite design. The example shows the condition in which the bottom halves (components in grey) are the attended halves. (b) Experiment timeline.

Figure 3. The composite effect in character perception was significant among the novices, but not the experts.

Figure 4. Three conditions in the follow-up experiment: upright (aligned), misaligned, and inverted.

Figure 5. The interaction between expertise and the congruency effect remained significant in the follow-up experiment when the experts' performance was degraded to a similar level to the novices' performance in the first experiment.

Figure 6. Misalignment significantly reduced the congruency effect observed in the novices (an interaction between congruency and misalignment in the novices, $p < 0.05$), but had no effect among the experts.

Figure 7. Inversion led to a congruency effect in the experts (an interaction between congruency and inversion in the experts, $p < 0.05$), but had no effect among the novices.

Figure 8. (a) Left chimeric, original, and right chimeric faces. (b) Left chimeric, original, and right chimeric characters, shown in Ming font. (c) Experiment timeline.

Figure 9. Left side bias effect in Chinese character perception among experts, but not novices.

Figure 10. (a) The left bias effect was reflected in the participants' eye fixation behavior: the experts' fixations were more to the left than novices'. (b) Distribution of the fixations onto the characters (collapsed over the four character locations on the screen) in all trials and from all subjects. On each fixation a Gaussian distribution with a standard deviation equal to eight pixels is applied to smooth the distribution (the image width is 81 pixels). The background shows the average of all character images in the materials.

Figure 1

Figure 2

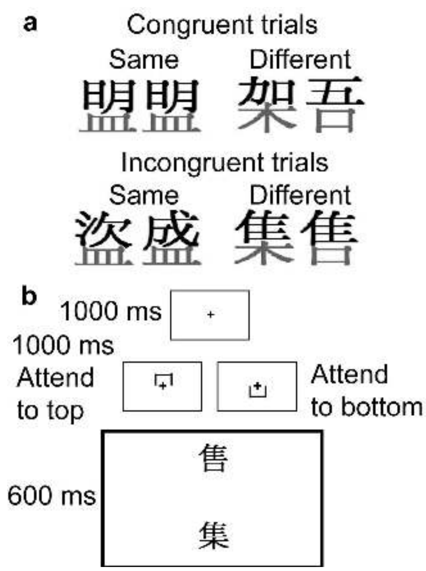

Figure 3

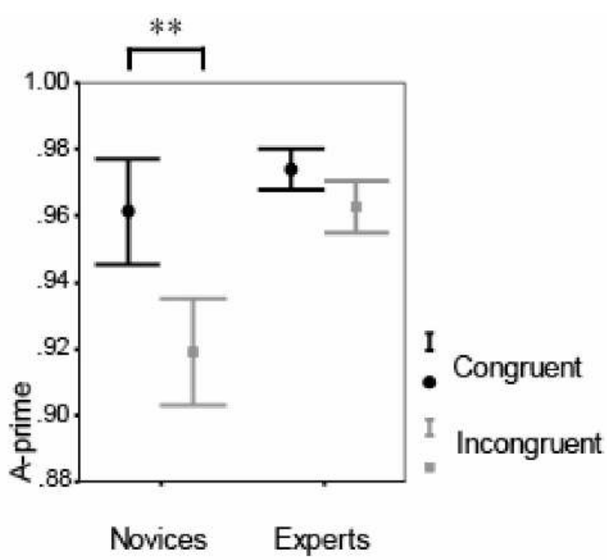

Figure 4

Figure 5

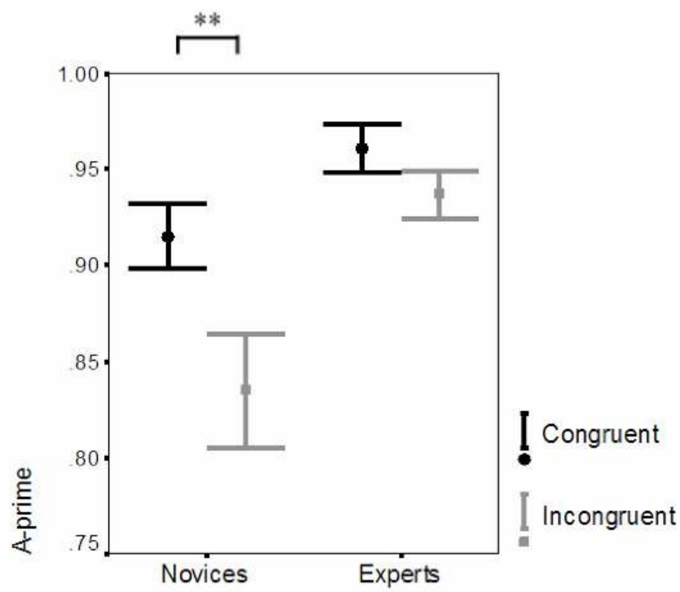

Figure 6

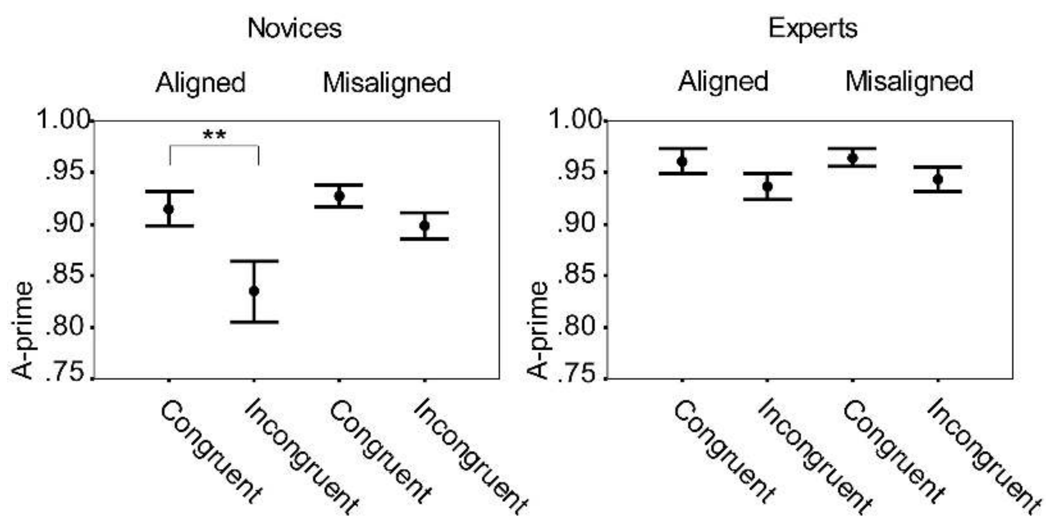

Figure 7

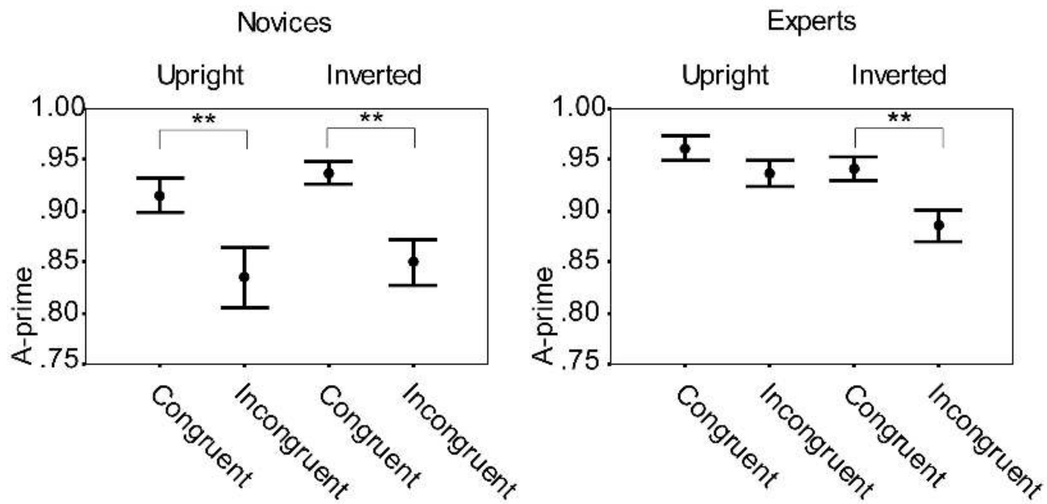

Figure 8

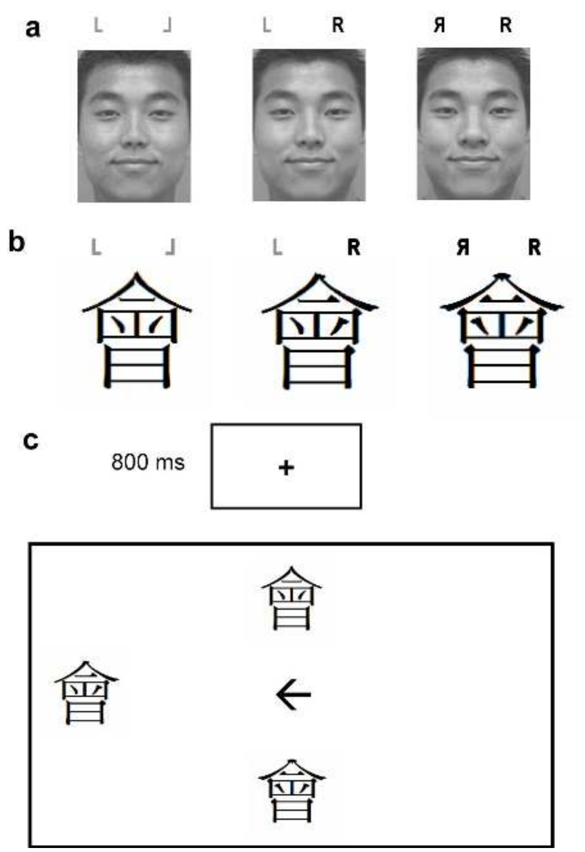

Figure 9

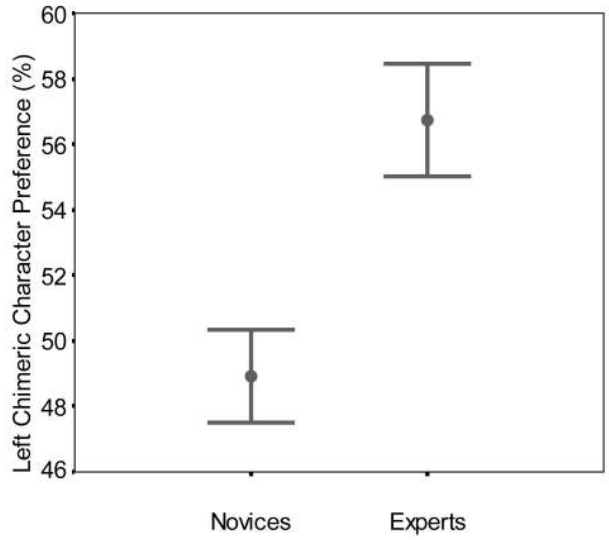

Figure 10