2011

Hemispheric Differences in Higher-Order Object Processing and Effect of Expertise: Modular vs. Distributed Perspectives

Cynthia S. Peng
Carnegie Mellon University

Hemispheric Differences in Higher-Order Object Processing and Effect of Expertise: Modular vs. Distributed Perspectives

Cynthia S. Peng

Department of Psychology

Carnegie Mellon University

In fulfillment of a B.Sc degree

April 2011

Advisor:

Marlene Behrmann, PhD

Professor, Department of Psychology

Carnegie Mellon University

Abstract

What is the process by which our brains recognize higher-order visual objects, like faces, words and foreign scripts? How does perception change with experience, and what are the implications for human behavior? We are interested in exploring the extent to which face processing and word processing are mediated by different or same hemispheric mechanisms, and the extent to which experience with a particular orthographic script (English, Chinese) influences this hemispheric specialization. Two groups of participants were recruited: those who have never formally studied Chinese, and whose native language is English, and those whose native language was Chinese, and acquired English as a second language. A split-field psychophysics paradigm tests for competition and cooperation across hemispheres when participants match displays of faces or words or Chinese characters presented in the left or right visual field. Accuracy and reaction time are compared for a left versus right visual field presentation to determine hemispheric gradation for these three classes of stimuli. Whereas native English speakers show a right hemisphere advantage for faces and left hemisphere advantage for words, native Chinese speakers show a left hemispheric advantage for faces and no hemispheric advantage for words. Both groups show a left hemispheric dominance for Chinese characters. The differences and similarity between the two groups brings to light the role of experience in object representation and the potential malleability of neural resources. Results have implications for perceptual expertise, cortical plasticity, and experience-dependent perceptual learning.

1. Introduction

Relative specialization of the left and right hemispheres of the brain has been well-established in neuropsychology. These hemispheric specializations play a role in the processing of higher-level visual stimuli, such as faces and words. It has been validated that the Fusiform Face Area (FFA), which gives rise to the perception of faces, predominantly resides in the right hemisphere (Kanwisher et al., 1997). An analogous area in the left hemisphere is the Visual Word Form Area (VWFA), which is selective for letter strings and underlies the ability to read (Cohen and Dehaene, 2004). The VWFA lies in the homologous occipitotemporal region in the left hemisphere.

The face module, termed the Fusiform Face Area, is located in the fusiform gyrus of the right hemisphere and is selectively activated by faces. It has been shown to respond more to human faces than animal or cartoon faces (Kanwisher, 2000) and is not affected by stimulus properties such as size, color, format, viewpoint, or retinal position. The FFA trumps all other regions for selectivity to faces, a class of stimuli that are ecologically relevant. On the other hand, words are an evolutionarily new phenomenon. Thus, the word module, commonly known as the Visual Word Form Area, is analogous in anatomical position to the FFA, but is selective for a category of stimuli that has anthropologically only been in existence for a few thousand years and requires explicit instruction to acquire. Overall, the VWFA responds selectively to visually presented words, more so than to line drawings and digits (Cohen et al., 2000; Cohen et al., 2003; Dehaene et al., 2005; Baker et al., 2007).

Damage to either area produces object recognition deficits. Prosopagnosia, known commonly as face blindness, occurs either congenitally or as a result of trauma, and impairs the ability to distinguish faces from each other. Individuals with prosopagnosia have shown a reduced degree of activation for faces in the fusiform region in neuroimaging studies (Avidan et al., 2005), and behaviorally perform poorly in tasks of fine-grained face discrimination where the faces are very similar. Prosopagnosia is considered a perceptual rather than mnemonic deficit; as patients utilize other characteristics, such as hair, voice, or clothing to identify the individual. Overall, prosopagnosia is often ascribed to a failure of configural processing (Barton et al., 2004; Barton et al., 2002), leading to part-by-part processing due to the lack of whole-face processing ability.

Similarly, damage to the VWFA produces alexia, the inability to read. Neuropsychological studies examining alexia with respect to the lesion site anatomically close to and overlapping with the VWFA have determined a type of alexia known as alexia-without-agraphia, also known as "pure word blindness" or "pure alexia" (Montant & Behrmann, 2000). Individuals with pure alexia show a linearly increasing reaction time with similarly increasing letter stream. Thus, those with pure alexia have mirroring characteristics of prosopagnosia in the sense that the constituent whole is broken down into letter-by-letter reading, showing overreliance on serial, laborious left-right spelling strategy (McCandliss et al., 2003; Warrington and Shallice, 1980). This lack of a global coherence in perceiving a word as a whole is much identifiable with the inability to perceive a face as a whole.

Overall, the FFA and VWFA differ in that they occupy different hemispheres of the brain, and are differentially affected via an individual's experience; whereas faces are ecologically relevant and naturally acquired, words are composed of an array of different logographic systems and require specific training and experience to become proficient. Thus, it is worthwhile to examine similarities and differences in the processing of these two higher-order stimuli, especially with regard to hemispheric similarities and differences.

Modular and Distributed: Interhemispheric Competition and Cooperation

Two perspectives pervade the literature on object representation at the higher cortical levels. On the one hand, as noted above, many findings point to category-specific modules dedicated to processing distinct classes of stimuli. In the past, neuroimaging and neuropsychological studies have favored the modular perspective: functional MRI studies show distinct activation in FFA for faces (Kanwisher et al., 1997) and VWFA for words (Dehaene et al., 2005), and patient studies point to category-selective deficits for prosopagnosia and pure alexia. Further arguments for competition, or modularity, is the fact that, given that language is lateralized to the left hemisphere, it would make sense on a functional neuroanatomical scale for the word region to also be on the left, as to minimize the “cost” in volume in neuronal interconnections.

However, there may be cooperation, or “distribution” in the sense that there is an inherent level of gradedness in the perception of these two categories of objects; specialization for faces or words may be a matter of degree and not restricted to the respective hemisphere. In more recent years, neuroimaging studies have shown that even highly specialized regions such as the FFA evince different patterns of BOLD signal in response to different categories of stimuli (Grill-Spector et al., 2006; Scherf et al., 2007). This indicates that highly specialized regions may be more optimized for, rather than purely dedicated to, their respective class of stimuli, and this optimization may vary with individual differences. Moreover, neuropsychological studies have shown that the VWFA and FFA are rather plastic. Patients with a left occipital resection in childhood (age 5) have acquired the VWFA in the right hemisphere (Cohen et al., 2004). Accordingly, those with unilateral lesions resulting from infancy that impacted just the right or left hemisphere have no face recognition deficits (de Schonen et al., 2005). This indicates the fact that neural plasticity with respect to these regions' processing capabilities is possible and that processing of the optimized class of stimuli may be accounted for in other cortical areas via shifting of neural resources.

Words and faces share many properties: susceptibility to crowding and a similar distance/spacing function (Martelli et al., 2005). Furthermore, one foundational theory to explain hemispheric differences relies upon the fact that the left hemisphere processes in a more analytical way whereas the right hemisphere processes more holistically (Hellige, 1993). Thus, it may be that faces and words engage in the same underlying cortical computations, but over different representations. Previous neuroimaging studies have shown bilateral activation for faces and words in the same individuals (Kanwisher et al., 1997; Kronbichler et al., 2004; Mercure et al., 2008; Price & Mechelli, 2005; Puce et al., 1996; Sergent et al., 1992; Tagamets et al., 2000), but the distribution of bilaterality in individuals is not known.

Chinese characters processing and the role of expertise in perception

Past studies of visual word perception have largely focused on the processing of alphabetic languages. More recently, researchers began investigating perceptual expertise with Chinese characters, which is a logographic system with pictorial representations. The Chinese language, which is visually and linguistically different from alphabetic scripts, consists of about 5000 characters composed of one to over 20 strokes (Yin and Rohsenow, 1994) and is opaque in the sense that the visual form in no way indicates the sound form of the character. As a result, learning Chinese requires high demands on the visuospatial memorization of the form and meaning of each character (Huang et al., 2004; Tan et al., 2005).

Hsiao and Cottrell (2009b) found that Chinese characters have a predominantly left hemisphere lateralization for expert readers of Chinese. One theory of this predominance by experts is due to left hemisphere superiority in phonological language processing, which is mediated by the left hemisphere. Another account is the visual characteristics of the word. English, a logographic system with a large lexicon size and small alphabet size, contrasts with Chinese, which has a small lexicon size but a large number of strokes. It has been suggested that experts' ability to bind the constituent strokes into a holistic representation substantiates the theory of a left hemisphere marker for expertise. However, this was found not to be the case, as novices showed an inability to selectively attend to character parts, whereas experts are able to break them down into their constituent strokes (Hsiao and Cottrell, 2009a). Thus, novices actually perceived the Chinese character more holistically than experts.

Furthermore, a similar bias has been found in faces. A long-established left visual field, right hemisphere bias has been found in studies with chimeric faces: 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). Hsiao and Cottrell (2009a) found that Chinese experts had a significant left chimeric character preference, whereas the novices did not have a preference. This suggests right hemisphere involvement in Chinese character expertise and that the right hemisphere has an advantage over the left hemisphere in tasks requiring processing of low frequency information.

Cao and colleagues (2010) also found electrophysiological evidence suggesting that Chinese reading is left hemisphere dominant. Using the N170 marker in ERP, which has been used to characterize the neural correlates of literary development and indicates a fast perceptual specialization for processing visual words (Maurer et al., 2005), Cao and colleagues studied the Chinese character processing abilities of 7, 9, and 11 year old Chinese schoolchildren. All groups, including the youngest children, showed an increased and left-lateralized N170 response for Chinese characters. Children as young as 7 showed this left lateralization, suggesting that perhaps the left lateralization emerges earlier than children learning alphabetic scripts (Cao et al., 2010). This was in line with previous studies, albeit studies with alphabetic languages, which have also found the N170 to be more prominent in the left hemisphere (Bentin et al., 1999; Maurer et al., 2005; Mercure et al., 2008). Moreover, the amplitude of the N170 decreased with age, showing perhaps an increase in speed for visual word processing, resulting from reading experience and neural maturation (Cao et al., 2010).

Another account for this N170 effect has been one of expertise; it has been found in the past that objects with which we have expertise elicits a greater N170 ERP response (Rossion, Gauthier, Goffaux, Tarr, & Crommelinck, 2002; Tanaka & Curran, 2001). Accordingly, Wong et al. (2005) recruited English-only and Chinese-English bilinguals and had them view Roman letters, Chinese characters, and pseudofonts. Subsequently, it was shown that a larger N170 response was noted at posterior channels for letters with which subjects have expertise – in this case, Roman letters for both English-only and Chinese-English bilinguals, along with Chinese characters for bilinguals. Wong and colleagues argue that the larger N170 for characters with which subjects have expertise may indicate that additional substrates are recruited for them, which contrasts with previous interpretations, which claim that the N170 waveform decreases with increased expertise (Cao et al., 2010).

Previous work has also established that experience alters Chinese character perception on a very early spatiotemporal time course. In comparing performance between Chinese speakers and a German control group, Elze and colleagues (2011) found that in a forced choice task where a mask of scrambled or intact Chinese characters preceded a Chinese character target, the Chinese speakers performed worse than their German counterparts. In the task, German controls would presumably perceive the mask-target combination as a transformation in arbitrary geometric objects, whereas Chinese speakers will perceive an object substitution of a meaningful object by a meaningful mask. Thus, the participants' different perceptual backgrounds influenced their judgments; the high degree of similarity between the mask and target for Chinese speakers impeded their ability to perform the target discrimination when the mask was presented temporally close to the target.

The Current Investigation

Understanding how these regions specialize in their respective category of stimuli will help in the understanding of the specific perceptual demands of each area. Cao and colleagues showed that the word perception-related N170 is most prominent in young readers (age 7) and decreases with age; however, it is acknowledged that those young children have received extensive exposures to reading Chinese characters before entering primary school. Thus, there is the need to elucidate and distinguish the role of experience by removing any exposure to the Chinese language. In this case, we recruited two populations of individuals - those who are native Chinese speakers who grew up in China, Hong Kong, Taiwan, and related territories, termed as "experts," and those who have never had formal or informal studies in Chinese and related orthographies but are otherwise proficient English readers, termed "novices," with the labels “expert” and “novice” pertaining only with respect to experience with the Chinese language. By testing two groups of people with drastically different experiences in orthography and language exposure, we hope to elucidate the role of experience in face and word perception more distinctly.

Previous neuroimaging studies have shown bilateral activation for faces and words in the same individuals (Kanwisher et al., 1997; Kronbichler et al., 2004; Mercure et al., 2008; Price & Mechelli, 2005; Puce et al., 1996; Sergent et al., 1992; Tagamets et al., 2000), but the distribution of bilaterality in individuals is not known. Moreover, a study examining the gradient of hemispheric competition and cooperation across these three categories of stimuli as a function of language experience has not been conducted, to the best of our knowledge. We aim to test this using psychophysics, whereby participants are asked to make rapid judgments on matching stimuli, and then by which accuracy and reaction times are recorded and compared across fields to test for hemispheric cooperation and competition.

Our predictions are as follows:

	FACES	WORDS	CHINESE CHARACTERS
Native English Speakers	Right hemisphere advantage	Left hemisphere advantage	No hemispheric advantage? More evenly graded
Native Chinese Speakers	Unclear	No hemispheric advantage? More evenly graded	Left hemisphere advantage

For native English speakers, face and word stimuli are expected to lateralize in the expected direction. In terms of Chinese characters, however, it is more unclear whether the native English speakers will perceive the foreign orthographic script as more left hemisphere, language-based, or right hemisphere, pictorially-based. Since it is an orthography in which the native English speakers have no experience, we predict that it may be more evenly graded, or at least not evince as strong of a left-hemisphere lateralization.

For native Chinese speakers, the effects are less clear. We predict that Chinese characters will have a left hemisphere lateralization much in the same way that English words are left lateralized for native English speakers. We also predict they will evince a less graded representation for English words, which is the second language for this population of individuals, and that this second language will be relegated to the right hemisphere since the left hemisphere is already utilized. Finally, representation of faces is unclear.

Moreover, it is established that 94% to 96% of healthy right-handers and 74% of left-handers have left-hemisphere language dominance (Pujol et al., 1999; Springer et al., 1999). However, hemispheric differences as a function of handedness is not clear, and we intend to investigate this across groups as well as a factor in gradedness. Overall, these findings will add to an understanding of how neural resources could be redistributed, which has implications for efficient utilization in the event of damage, as well as how language as a marker of expertise can alter behavioral and neurophysiological components across populations.

2. Experimental Methods

2.1 Participants

Participants were undergraduate and graduate students at Carnegie Mellon University. 45 participants took part in the behavioral study; separated into two groups: native English speakers (n=24; 9 male and 15 female), and Chinese-English bilinguals whose first language was Chinese (n=21; 8 male and 13 female). Of the English-only group, none indicated previous experience with or study of Chinese or similar languages, and all grew up in Western cultures. Of the Chinese-English bilinguals, all were born in China, Taiwan, or Hong Kong, and lived the in that environment for a minimum of 10 years before immigration to the U.S. All reported extensive experience in reading Chinese (self-indicated as reading Chinese text at least 30% of the time), as well as daily exposure to Chinese.

Participants were recruited through the Psychology participant pool and received class credit, or through the campus community at large and received $10 compensation. All participants were right handed, with a mean score of 73.5 on the Edinburgh Handedness Inventory (Oldfield, 1971), with a range of scores from 23 to 100. Participants ranged in age from 18 to 66 years, with a mean age of 22.2. Native English speakers had a mean age of 19.3 while native Chinese speakers had a mean age of 25.6. This discrepancy in age is due primarily to the fact that the native English speakers were mostly underclassmen completing the experiment in fulfillment of an introductory psychology class requirement, and the native Chinese speakers were primarily master's level or doctorate students. All participants completed the Faces, English Word, and Chinese Character experiments in a single session in a counterbalanced fashion, with a short break between the experiments.

2.2 Stimuli

2.2.1 Faces

Face stimuli consisted of 18 grayscale faces: 9 male, 9 female (Figure 1). For each trial (see below), female faces were paired only with female faces, and male with male. Faces had an approximate size of 7 x 25 mm on the screen. The similarity of faces were standardized to each other via a luminance comparison, which was computed via the luminance difference between gray pixels between two faces. This standardization provided a meaningful measure of difference values within a category, as to ensure that visual discrimination is not due to sharp luminance contrasts alone. Thus, each pair of faces presented was selected as to have very small difference values.

2.2.2 English Words

The word stimuli included 28 pairs of four letter English words with the outer 2 letters different, the inner 2 letters the same (Figure 2), i.e. "PANT" and "BAND." Words were presented in Courier font, size 36, white against a black background. Words were also standardized via a luminance comparison in a similar fashion to that performed on faces, except it was the difference between black and white pixels that were computed.

2.2.3 Chinese Characters

These stimuli included 28 pairs of single Chinese characters (Figure 3). Throughout the pair, the outer radical remained the same while the content inside was different. This mirrored the same/different component arrangement for English words. The characters varied in complexity in the number of strokes. Presented characters had an approximate size of 7 x 25 mm on the screen. They were standardized via a luminance comparison, where the difference between black and white pixels were computed.

2.3 Design and Procedure

Each of the Faces, English words, and Chinese characters experiments followed the same paradigm. Each trial consisted of a fixation duration of 2500 ms, followed by a single "target" stimulus which was presented in the center of the screen for 150 ms. At the offset of this stimulus by two stimuli, one positioned 2.5 degrees to the left of center and the other positioned 2.5 degrees to the right of center, were presented simultaneously for 150 ms. One of the two stimuli was a "match" for the single target and the match could appear on the left or right with equal probability. Participants were instructed to press the 'z' key if the match appeared in the left visual field and 'm' if the match appeared in the right visual field. Both reaction time (RT) and accuracy were recorded and after a response was indicated, the next trial was initiated. Participants were asked to fixate on a central fixation cross throughout the experiment, as to prevent saccades and thus shifting attention.

This rapidly-presented psychophysics paradigm (Figure 4) capitalizes on the “crossing” of the human nervous system. Due to the fact that the visual field is crossed at the optic chiasm, information from the left visual field is relayed to the right hemisphere, and information from the right visual field is relayed to the left hemisphere. Thus, due to this inherent crossing, judgments made by the participant reflect the automaticity of this neuroanatomical design. Also, because the exposure duration of both the target and the match stimuli is of brief duration, saccades are not possible and hence, the stimuli are directed to one or the other hemisphere for processing. In this way, we can assay the relative contribution of each hemisphere to processing the three stimulus types.

Stimulus presentation within a block of trials was randomized and controlled by the E-prime experiment package. For each of the three experiments, there were 6 blocks of 28 trials each, with a brief rest period between each block. Each experiment thus consisted of 168 trials total, split evenly into left target-match trials and right target-match trials.

The conditions create a 2 by 2 by 3 design with the within-subjects variables of hemisphere (left vs. right) and category of stimuli (faces vs. English words vs. Chinese characters), and this was fully crossed with the between-subjects variable (native English speakers vs. native Chinese speakers).

3. Results

Although we collected RT as well as accuracy data, given the brief exposure duration and data-limited processing, accuracy is the more appropriate dependent measure to consider and so we focus specifically on accuracy here.

A repeated measures ANOVA was performed to examine accuracy (percentage correct) with visual field and trial type as within-subjects factors.The ANOVA revealed a main effect for left versus right hemisphere ($F(1,44) = 10.30$, $P < 0.05$), with higher accuracy for the left than right hemisphere (LH = 96.3; RH = 94.7). There was an interaction between Category by Hemispheres ($F(1,44) = 5.67$, $P < 0.05$) as well as Category by Expertise ($F(1,44) = 5.61$, $P < 0.05$), both of which were modulated by the remaining factor, as evidenced in the three-way interaction between Category, Expertise, and Hemisphere ($F(1,44) = 7.31$, $P < 0.05$).

In examining the hemispheric differences by group, significant within-subject effects emerged. In the native English speaking group (Figure 5), all three categories emerged as significant with regards to hemispheric differences, with a left hemisphere advantage for words ($F(1,23) = 3.46$, $P = 0.002$) and a right hemisphere advantage for faces ($F(1,23) = 2.24$, $P = 0.035$). Chinese characters produced a left hemisphere advantage ($F(1,23) = 3.22$, $P = 0.004$). Within English-only speakers, there were main effects of Hemispheres ($P = 0.016$; with LH = 92.0, RH = 90.4) and Category ($P = 0.011$; with faces = 92.6; words = 92.4, and Chinese characters = 88.7). The magnitude of left hemispheric advantage for words (LH – RH difference = 2.36) was greater than the magnitude of right hemispheric advantage for faces (RH – LH difference = 1.67). Moreover, the magnitude of left hemisphere advantage was greatest for Chinese characters (LH – RH difference = 4.11). There was also a significant interaction of Hemispheres by Category ($P = 0.002$). Additionally, we were able to simultaneously compare all 3 types of stimuli on by individuals and discern what percentage of the participants fell in the expected direction.

Table 2. Native English Speakers – Accuracy by Category and Hemisphere

	Faces	**Words**	**Chinese Characters**	**Average by Hemisphere**
Left Hemisphere	91.8	93.5	90.7	92.0
Right Hemisphere	93.4	91.2	86.6	90.4
Average by Category	92.6	92.4	88.7	91.2
Extent of Left Hemisphere Advantage (LH – RH)	-1.67	2.36	4.11	1.60
% of Participants Showing Lateralization in Expected Direction	67%	79%	79%	

In the native Chinese speakers group (Figure 7), the hemispheric difference between two categories emerged as significant. There was a left hemisphere advantage for Chinese characters ($F(1,20) = 3.55$, $P = 0.002$) as well as Faces ($F(1,20) = 2.57$, $P = 0.018$). There was no significant difference between hemispheres for Words, with both hemispheres performing at about the same level of accuracy. The magnitude of left hemispheric advantage for Chinese characters (LH – RH difference = 2.28) was greater than the magnitude of right hemispheric advantage for faces (RH – LH difference = 1.67). Moreover, there was virtually no difference between hemispheres for words (LH – RH difference = 0.12).

Table 3. Native Chinese Speakers – Accuracy by Category and Hemisphere

	Faces	**Words**	**Chinese Characters**	**Average by Hemisphere**
Left Hemisphere	96.1	96.2	98.1	96.8
Right Hemisphere	95.4	96.0	95.8	95.4
Average by Category	96.1	96.1	97.0	96.1
Extent of Left Hemisphere Advantage (LH – RH)	1.36	0.12	2.28	1.36
% of Participants Showing Lateralization in Expected Direction	81%	67%	81%	

Due to the fact that performance was high for both groups (Native English speakers overall accuracy = 91.2; Native Chinese speakers overall accuracy = 96.1), we removed 1/3 of the top performers in each group to account for a possible ceiling effect. Results still showed the same underlying pattern. Native English speakers evinced a left hemisphere advantage for words ($F(1,15) = 3.40$, $P = 0.004$) and a right hemisphere advantage for faces ($F(1,15) = 2.31$, $P = 0.036$). Likewise, Chinese characters produced a left hemisphere advantage ($F(1,15) = 2.80$, $P = 0.013$).

Accordingly, the Chinese-English bilingual group with the upper 1/3 removed produced similar results as the group in its entirety, with a left hemisphere advantage for Chinese characters ($F(1,14) = 3.65$, $P = 0.003$) and a left hemisphere advantage for faces ($F(1,14) = 2.71$, $P = 0.017$), and no hemispheric advantage for words ($F(1,14) = 0.80$, $P = 0.437$).

4. Discussion

In considering the two disparate groups – native Chinese speakers and native English speakers – we acknowledged that there would be significant within-group variability in hemispheric differences. In the native English speaking group, hemispheric differences in all three categories proved significant. Two of the effects – faces and words – evinced a right and left hemispheric advantage, respectively, which abetted previous findings. However, when viewing Chinese characters, English speakers showed a left hemisphere advantage, which was counterintuitive to novices' processing of foreign scripts. Previous studies have indicated that novices to the Chinese orthography perceive the characters more holistically than experts (Hsiao and Cottrell, 2009a), due to the fact that experts have a better awareness in breaking down the individual components of characters, whereas novices do not. This would, in theory, be mediated largely by the right hemisphere. However, in a study with similarly recruited groups, Nelson and colleagues (2009) scanned English-only speakers and Chinese-English bilinguals and found that the English-only group showed left-lateralized activity when viewing English stimuli but bilateral activity when viewing Chinese stimuli, showing more support for at least some processing weight occurring in the left hemisphere for Chinese characters in novices. Consistent with our findings, there was a significant category by stimulus interaction, though the Nelson study included pseudowords in addition to English words and Chinese characters as opposed to faces. Moreover, Nelson et al. showed that all of the native English speakers showed an increase in activation for Chinese than for English in the right fusiform. Our study was in contrast to this finding, as all but five native English speakers showed greater accuracy on the left. Another explanation proposed by Tan et al. (2003) attributes this effect to left hemisphere cortical regions that are known to contribute to spatial information representation, spatial working memory, and coordination of cognitive resources. Novices to Chinese may be drawing upon this neural system to process the Chinese orthography, which is drastically different from the English orthography and subsequent logographic processing, most efficiently.

In the native Chinese speakers (expert) group, two interesting effects of hemispheric advantage went against the expected result. English words elicited no hemispheric difference while faces elicited a left hemispheric advantage, which is counterintuitive to previous findings. With regard to English word perception, several explanations abide. Nelson et al (2009) found in an fMRI study that native Chinese speakers who acquired English as a second language recruited bilateral fusiform areas when viewing both Chinese and English stimuli. Of note is the fact that these native Chinese speakers in both our experiment and in that of Nelson et al were mostly undergraduate and graduate students who have completed their education at least through high school in China and acquired English to a fluent or near-fluent extent in their formal education. Thus, their bilingualism plays a role in distinguishing them from Chinese-only speakers in the sense that Chinese-English bilinguals may be using overlapping regions for reading in the two hemispheres (Nelson et al., 2009), but that these regions may not be the same ones recruited in monolingual speakers in both languages. Thus, having the native language of Chinese already existing in the left hemisphere, the acquisition of a second language may have been “pushed” to the right hemisphere in a more bilateral representation. This shifting of neural resources is what Perfetti and Liu (2005) would refer to as the System Accommodation Hypothesis, by which the brain must accommodate the new language by recruiting neural structures that can support the specific processing demands of the new writing system. In doing so, the Chinese-English bilingual participants in our study show an equivocal response for English words since the left-hemisphere dominance has already predominated with Chinese, their native language. Our results contradict that of the System Assimilation Hypothesis, which refers to the fact that the brain structures already functional for the writing system of the first language will be transferred to the second language to some extent. Should this be true, we should also see a left hemisphere advantage for the second language – English words – in this group, but this is not the case.

English-Chinese bilingual participants also evince a left hemisphere advantage for faces, which is contradictory to the neuropsychological basis of right-hemisphere FFA dominance. This effect may be explained by the role of expertise. Hsiao and Cottrell (2009a) found that Chinese experts have a left hemisphere advantage for mirror-symmetric characters. Accordingly, faces are similar in this regard, which may explain this analogous finding. Though the Chinese characters utilized in our experiment were not mirror-symmetric characters, a proportion of the Chinese language is, and years of experience with this aspect of the language may have altered the perception of other categories as well. This left hemisphere dominance effect is found even in imposed situations, such as constructing a chimeric pseudo-character constructed out of mirror-reversing half of a real character (Hsiao and Cottrell, 2009a).

Overall, our study highlights several marked findings. First, hemispheric differences exist and do come into prominence when making rapid judgments with faces, English words, and Chinese characters. Some follow neuroanatomical convention and others contradict previous findings. Moreover, these hemispheric differences vary as a function of expertise, as evidenced by the differing dominance patterns in the two populations. These behavioral results may be further applied to the System Accommodation Hypothesis, which puts forth that additional neural structures are recruited for the learning of a second language. In this regard, we have shown that the native language of the two groups evince similar hemispheric patterns: both the Chinese characters for native Chinese speakers and English words for native English speakers show a significant left hemispheric advantage. This LH advantage for one's native language is similar in magnitude between the two groups. However, the pattern for second language acquisition – as shown by performance on English words in native Chinese speakers – does not evince the same pattern. We have only examined second language acquisition one way: by examining the English word processing capabilities of native Chinese speakers. To fully discern this effect, further studies are needed which recruit an analogous group of native English speakers who are learning Chinese.

We have shown that performance on split-field judgments on higher-order visual stimuli can be altered with experience and that expertise with a previous language underlies these differences. With regard to the modularity vs. distribution hypotheses, our findings speak to both. Behavioral evidence with English-only speakers firmly abets the existing modular neuropsychological literature for faces and words. The existence of a largely right hemisphere FFA and left hemisphere VWFA is supported by these results. Competition for faces and words exist in the sense that there is a clear increase in performance when faces are presented to the right hemisphere and words to the left. For Chinese-English bilinguals, especially with regard to English words, modularity is less clear. With no clear hemispheric advantage, these individuals point to the fact that neural resources may be shifted in acquiring this second-language system. Having already taken on a clear left hemispheric advantage for the first language, the two hemispheres must now work in tandem in order to process the visual properties of English words, leading to a less graded representation across hemispheres. Thus, as a function of experience, there is evidence for cooperation.

The knowledge garnered from this and subsequent studies provide evidence that expertise can alter the representation of complex visual objects in the cortex. This work may have applications for educational outcomes in second language acquisition as well as cortical plasticity in the adult brain. The shifting of neural resources can help researchers understand the mechanisms behind the development of expertise, and how that expertise generalizes to all subsets of stimuli in that class or just specific instances. One of the most practical real-world benefits of this research is its applications to individuals with cortical damage; in particular visual agnosia. Should a specific area be damaged, such as the VWFA, the patients' ability to read may not be completely eliminated; but rather the other subsidiary cortical areas also responsible for reading may be strengthened and trained to take on a bigger portion of the task it was not previously fully assigned. These studies will be the basis of future experiments with different classes of expertise-laden stimuli and how visual acquisitions of them are obtained, opening up many implications for behavior on how people learn and develop expertise.

References

Avidan, G., Hasson, U., Malach, R., & Behrmann, M. (2005). Detailed Exploration of Face-related Processing in Congenital Prosopagnoisa: 2 Functional Neuroimaging Findings. *The Journal of Cognitive Neuroscience, 17(7),* 1150-67.

Baker, C.I., Liu, J., Wald, L.L., Kw ong, K.K., Benner, T., & Kanwisher, N. (2007). Visual word processing and experiential origins of functional selectivity in human extrastriate cortex. *Proceedings of the National Academy of Sciences, 104(21),* 9087-92.

Barton, J. J. S., Cherkasova, M. V., Press, D. Z., Intriligator, J. M., & O'Connor, M. (2004b). Perceptual functions in prosopagnosia. *Perception, 33*(8), 939-956.

Barton, J. J. S., Press, D. Z., Keenan, J. P., & O'Connor, M. (2002). Lesions of the fusiform face area impair perception of facial configuration in prosopagnosia. *Neurology, 58*(1), 71-78.

Bentin, S., Mouchetant-Rostaing, Y., Giard, M.H., Echallier, J.F., & Pernier, J. (1999). ERP manifestiations of processing printed words at different psycholinguistic levels: time course and scalp distribution. *Journal of Cognitive Neuroscience, 11,* 235-260.

Cao, X., Li, S., Zhao, J., Lin, S., & Weng, X. (2010). Left-lateralized early neurophysiological response for Chinese characters in young primary school children. *Neuroscience Letters, 492(3),* 165-69.

Cohen, L., & Dehaene, S. (2004). Specialization within the ventral stream: the case for the visual word form area. *Neuroimage, 22,* 466-76.

Cohen, L., Dehaene, S., Naccache, L., Lehericy, S., Dehaene-Lambertz, G., Henaff, M. A., et al. (2000). The visual word form area: Spatial and temporal characterization of an initial stage of reading in normal subjects and posterior split-brain patients. *Brain, 123 (Pt 2)*, 291-307.

Cohen, L., Lehericy, S., Henry, C., Bourgeois, M., Larroque, C., Sainte-Rose, C., et al. (2004b). Learning to read without a left occipital lobe: Right-hemispheric shift of visual word form area. *Ann Neurol, 56*(6), 890-894.

Cohen, L., Martinaud, O., Lemer, C., Lehericy, S., Samson, Y., Obadia, M., et al. (2003). Visual word recognition in the left and right hemispheres: Anatomical and functional correlates of peripheral alexias. *Cerebral Cortex, 13*, 1313-1333.

Compton, R. (2002). Inter-hemispheric interaction facilitates face processing. *Neuropsychologia, 40,* 2409-19.

Elze, T., Song, C., Stollhoff, R., Just, J. (2011). Chinese characters reveals impacts of prior experience on very early stages of perception. *BioMed Central Neuroscience, 12:* 14.

Grill-Spector, K., Sayres, R., & Ress, D. (2006). High-resolution imaging reveals highly selective nonface clusters in the fusiform face area. *Nature Neuroscience, 9*(9), 1177-1185.

Hellige, J. (1993). Hemispheric asymmetry: What's right and what's left. Cambridge, MA: Harvard University Press.

Hsiao, J.H., & Cottrell, G.W. (2009a). Not all visual expertise is holistic, but it may be leftist: The case of Chinese character recognition. *Psychological Science, 20(4)*, 455-463.

Hsiao, J. H., & Cottrell, G. W. (2009b). What is the cause of left hemisphere lateralization of English visual word recognition? Pre-existing language lateralization, or task characteristics? *Proceedings of the Thirty-First Annual Conference of the Cognitive Science Society*. Mahwah, NJ: Lawrence Erlbaum Associates.

Hsiao, J. H., & Cottrell, G. W. (2008). Two fixations suffice in face recognition. *Psychological Science, 9(10),* 998-1006.

Hsiao, J. H., Shahbazi, R., & Cottrell, G. W. (2008). Hemispheric asymmetry in visual perception arises from differential encoding beyond the sensory level. *Proceedings of the Thirtieth Annual Conference of the Cognitive Science Society.* Mahwah, NJ: Lawrence Erlbaum Associates.

Hsiao, J.H., Shieh, D., & Cottrell, G. (In press). Convergence of the visual field split: Hemispheric modeling of face and object recognition.

Huang, K., Itoh, K., Suwazono, S., & Nakada, T. (2004). Electrophysiological correlates of grapheme-phoneme conversion. *Neuroscience Letters, 366,* 254-258.

Hutsler, J., & Galuske, R.A.W. (2003). Hemispheric asymmetries in cerebral cortical networks. *Trends in Neurosciences, 26,* 429-435.

Kanwisher, N., McDermott, J., & Chun, M.M. (1997). The Fusiform Face Area: A Module in Human Extrastriate Cortex Specialized for Face Perception. *The Journal of Neuroscience, 17(11),* 4302-11.

Kanwisher, N. (2000). Domain specificity in face perception. *Nature Neuroscience, 3*(8), 759-763.

Kronbichler, M., Hutzler, F., Wimmer, H., Mair, A., Staffen, W., & Ladurner, G. (2004). The visual word form area and the frequency with which words are encountered: Evidence from a parametric fMRI study. *Neuroimage, 21*(3), 946-953.

Leder, H., & Bruce, V. (2000). When inverted faces are recognized: The role of configural information in face recognition. *Q J Exp Psychol A, 53*(2), 513-536.

Liu, C., Zhang, W.T., Tang, Y.Y., Mai, X.Q., Chen, H.C., Tardif, T., & Luo, Y.J. (2008). The Visual Word Form Area: Evidence from an fMRI study of implicit processing of Chinese characters. *NeuroImage, 40,* 1350 – 1361.

Martelli, M., Majaj, N. J., & Pelli, D. G. (2005). Are faces processed like words? A diagnostic test for recognition by parts. *Journal of Vision, 5*, 58-70.

Maurer, U., Brem, S., Bucher, K., Brandeis, D. (2005). Emerging neurophysiological specialization for letter strings. *Journal of Cognitive Neuroscience, 17,* 1532-52.

Maurer, D., Le Grand, R., & Mondloch, C. J. (2002). The many faces of configural processing. *TRENDS in Cognitive Sciences, 6*(6), 255-260.

McCandliss, B. D., Cohen, L., & Dehaene, S. (2003). The visual word form area: Expertise for reading in the fusiform gyrus. *Trends Cogn Sci, 7*(7), 293-299.

Mercure, E., Dick, F., Halit, H., Kaufman, J., and Johnson, M.H. (2008). Differential lateralization for words and faces: category or psychophysics? *Journal of Cognitive Neuroscience, 20,* 2070-2087.

Montant, M., & Behrmann, M. (2000). Pure alexia: Review of cases. *Neurocase, 6*, 265-294.

Nelson, J.R., Liu, Y., Fiez, J., Perfetti, C.A. (2009). Assimilation and Accommodation Patterns in Ventral Occipitotemporal Cortex in Learning a Second Writing System. *Human Brain Mapping, 30,* 810-820.

Perfetti, C.A., Liu, Y. (2005). Orthography to phonology and meaning: Comparisons across and within writing systems. *Reading Writing, 18,* 193-210.

Puce, A., Allison, T., Asgari, M., Gore, J. C., & McCarthy, G. (1996). Differential sensitivity of human visual cortex to faces, letterstrings, and textures: A functional magnetic resonance imaging study. *The Journal of Neuroscience, 16*(16), 5205-5215.

Pujol, J., Deus, J., Losialla, J.M., Capdevilla, A., (1999). Cerebral lateralization of language in normal left-handed people studied by functional MRI. *Neurology, 52,* 1038-43.

Price, C. J., & Mechelli, A. (2005). Reading and reading disturbance. *Curr Opin Neurobiol, 15*(2), 231-238.

Rossion, B., Gauthier, I., Goffaux, V., Tarr, M.J., & Crommerlinck, M. (2002). Expertise training with novel objects leads to left-lateralized facelike electrophysiolgical responses. *Psychological Sciences, 13,* 250-257.

Scherf, K. S., Behrmann, M., Humphreys, K., & Luna, B. (2007). Visual category-selectivity for faces, places and objects emerges along different developmental trajectories. *Developmental Science, 10*(4), 15-30.

Sergent, J., Ohta, S., & MacDonald, B. (1992a). Functional neuroanatomy of face and object processing. *Brain, 115*, 15-36.

Tagamets, M. A., Novick, J. M., Chalmers, M. L., & Friedman, R. B. (2000). A parametric approach to orthographic processing in the brain: An fMRI study. *Journal of Cognitive Neuroscience, 12*(2), 281-297.

Tan, L.H., Spinks, J., Eden, G., Perfetti, C.A., & Siok, W.T. (2005). Reading depends on writing, in Chinese. *Proceedings of the National Academy of Sciences, 102,* 8781-85.

Tanaka, J.W., & Curran, T. (2001). A neural basis for expert object recognition. *Psychological Science, 12,* 43-47.

Warrington, E. K., & Shallice, T. (1980). Word-form dyslexia. *Brain, 103*, 99-112.

Wong, A., Gauthier, I., Woroch, B., DeBuse, C., Curran, T. (2005). An early electrophysiological response associated with expertise in letter perception. *Cognitive, Affective, & Behavioral Neuroscience, 5(3),* 306-318.

Xue, G., Chen, C., Jin, Z., & Dong, Q. (2006). Language experience shapes fusiform activation when processing a logographic artificial language: An fMRI training study. *NeuroImage, 31,* 1315 – 1326.

Yin, B., & Rohsenow, J.S. (1994). Modern Chinese Characters, Beijing: Sinolingua.

Figure 1. Example of face stimuli

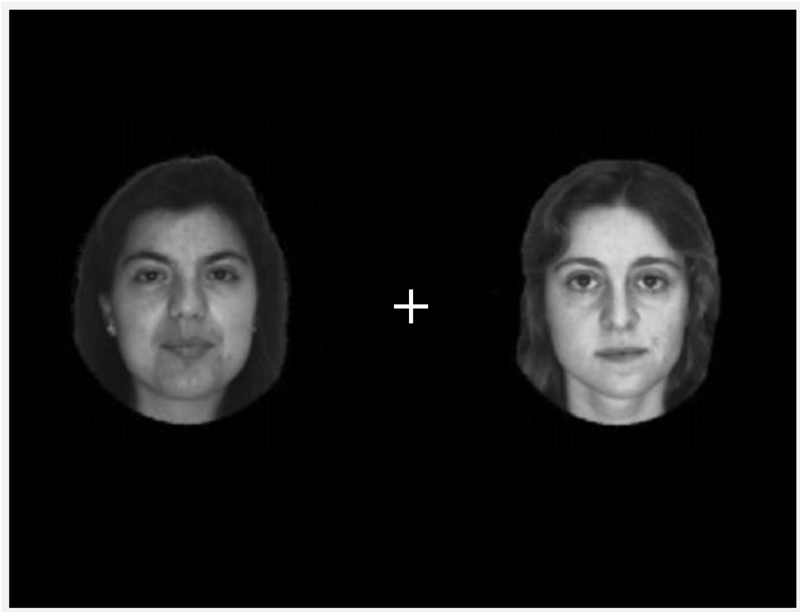


Figure 2. Example of word stimuli

Figure 3. Example of Chinese character stimuli

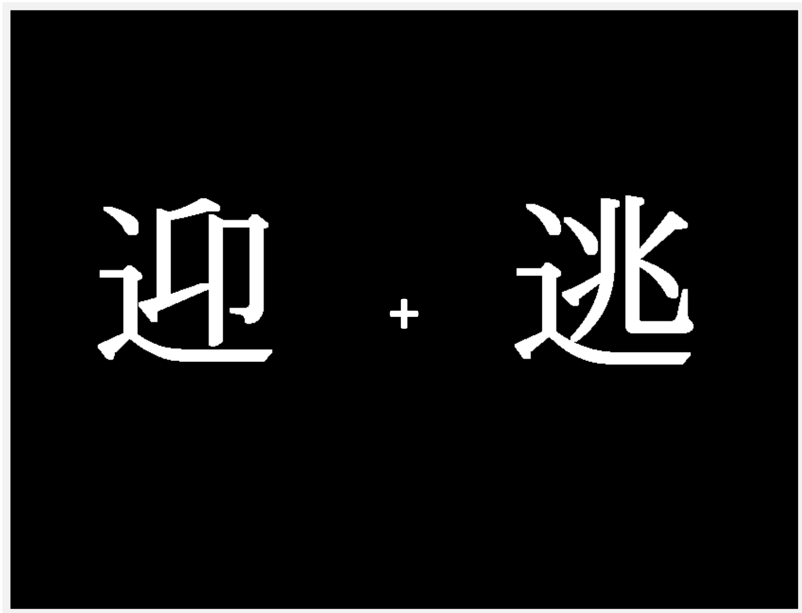
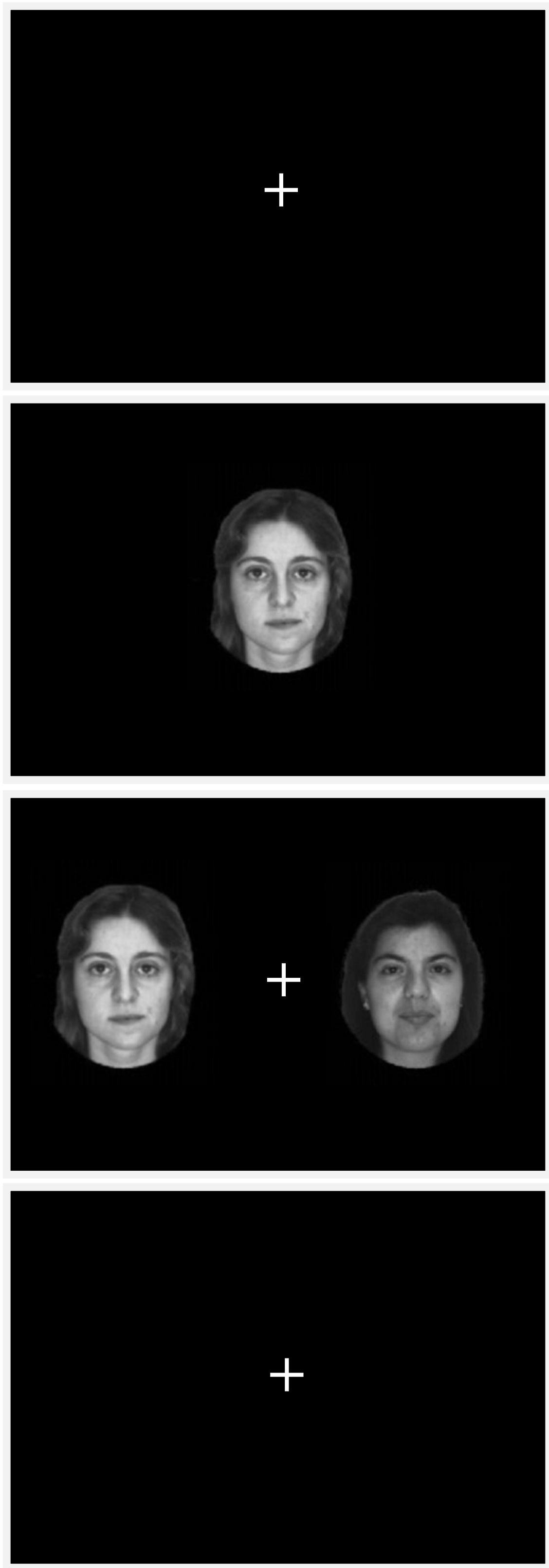


Figure 4. Sequence of a trial



2500 ms

150 ms

150 ms
Participant indicates a response

Screen goes back to fixation until the next trial begins

Figure 5. English-only Speakers (Novices) – Accuracy

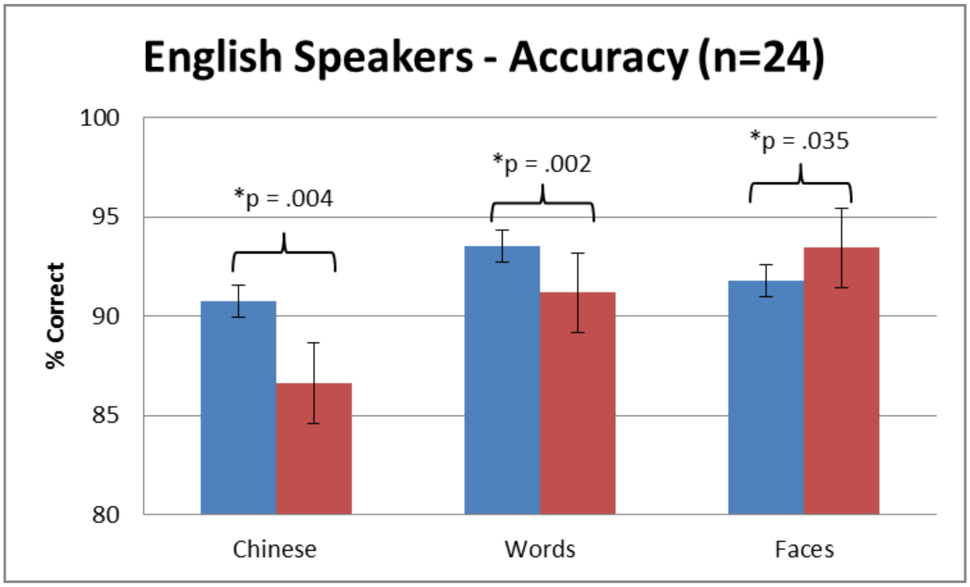


Figure 6. English-only Speakers (Novices) – Reaction Time

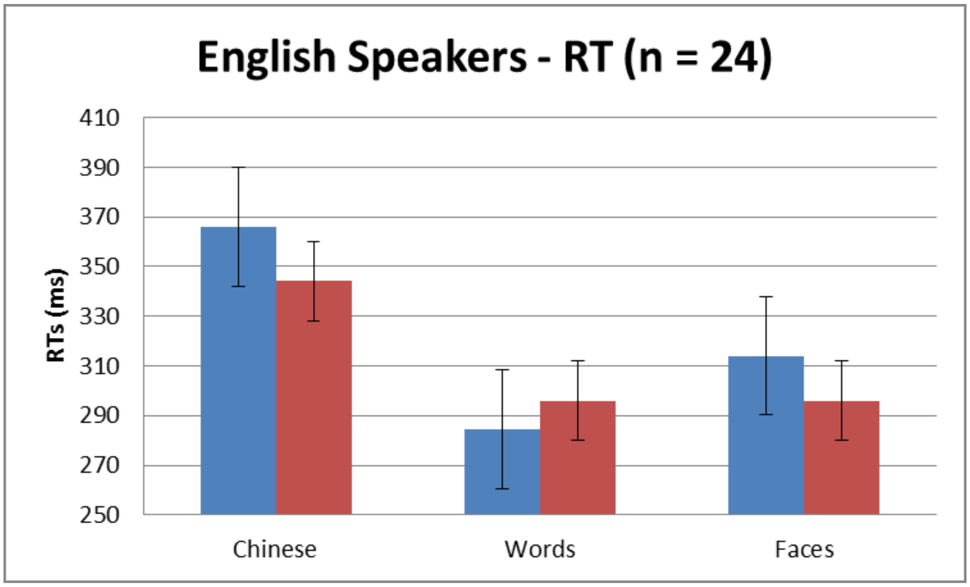


Figure 7. Chinese-English Bilinguals (Experts) – Accuracy

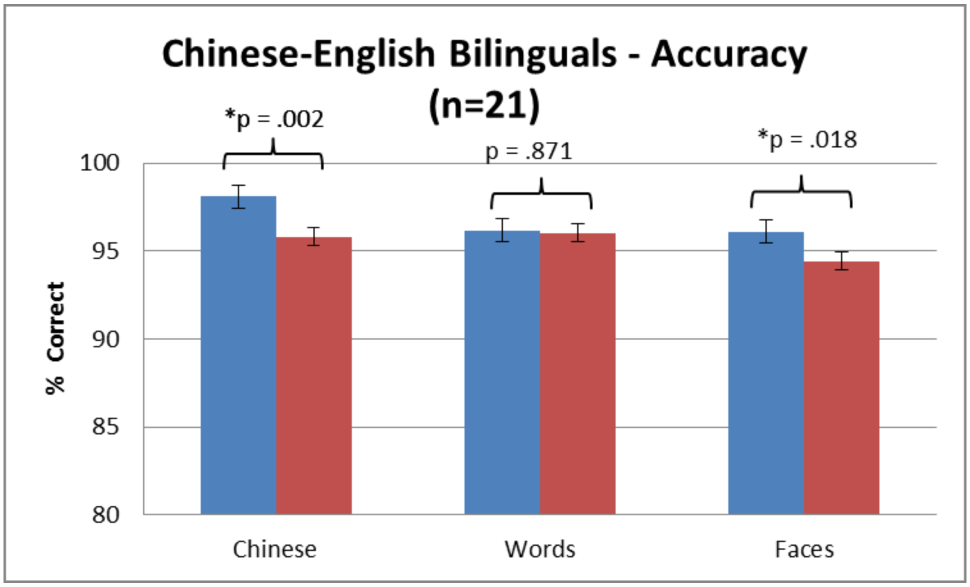


Figure 8. Chinese-English Bilinguals (Experts) – Reaction Time