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Effects of Long-Time Reading Experience on Reaction Time and the Recognition Potential

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Abstract

The proposition that long-time experience in reading a language gradually builds up rapidly acting neural processes that facilitate the processing of words in that language and speed them into conscious awareness was examined. Behavioral reaction time (RT) and electrophysiological responsiveness to visually displayed words and non-language images were measured in persons who differed in how much experience they had in reading English. The electrophysiological response was the recognition potential (RP). Behavioral RT and the latency of the RP to English words were both expected to depend upon how much English reading experience a person had. The short latency of the RP was expected to free it from the influence of non-perceptual factors that affect RT, such as speed/accuracy tradeoff. This expectation yielded the prediction that the behavioral and electrophysiological results would differ in a specific way. Long-time readers of English were expected to show shorter RP latency to English words than less experienced (China-educated) readers of English but no RP latency difference for non-language images, with which neither group had greater experience. In contrast, due to speed accuracy tradeoff, the China-educated subjects were expected to show longer RT for both the words and the non-language images. The prediction was confirmed. The amount of language experience that a person had showed a stronger relationship to RP latency than it did to RT. This helped to validate the use of the RP as a tool for investigating perception and demonstrated definite advantages that it has for studying acquired perceptual processes in humans.

Keywords

recognition potential; perception; language; reading; gestalt; word recognition

1. Introduction

The recognition potential (RP) is an electrical response of the brain that is evoked by recognizable images, such as words, pictures, or faces (Rudell, 1990, 1991). Words displayed in a person's primary language rapidly evoke the RP, but words in an unfamiliar language, such as Arabic or Chinese, do not (Rudell, 1992). The generators of the RP seem to have an occipital locus (Rudell et al., 1993). Hinojosa et al. (2001b) pinpointed them to the fusiform/lingual gyri. The same generators seemed to be involved in the processing of words and pictures (Hinojosa et al., 2000; Martín-Loeches et al., 2001a; 2001b). Brain stimulation studies show

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that this area is closely connected to visual perception (Amassian et al., 1989; Maccabee et al., 1991). A single transcranial magnetic pulse applied to it blocks the perception of language or non-language images if it is delivered about 100 ms after the image is displayed.

Short latency is an important feature of the RP that distinguishes it from longer latency event-related potentials. The RP reaches a peak about 200 to 300 ms after the onset of a recognizable image. Its latency depends on the experimental conditions. This characteristic suggests that it could be used as an indicator of the speed of perceptual processing. Many variables that presumably influence the speed of perception affect the latency of the RP in the expected direction. The addition of a moderate amount of noise to word images, for example, significantly increased RP latency (Rudell and Hua, 1995). If enough noise is added, the amplitude of the RP begins to decrease. It disappears altogether if the added noise is so great that the words become unrecognizable. Thus, the amplitude of the RP is affected by experimental variables. However, RP amplitude tends to be a less sensitive measure than RP latency is. Repetition priming, for example, significantly decreased RP latency to words without significantly affecting the amplitude of the RP (Rudell and Hua, 1996b). In another study, RP latency was significantly less for words frequently used in literature than for rarer words, but RP amplitude did not differ significantly, despite a very strong word frequency effect on the latency of the RP (Rudell, 1999).

Though it is sensitive to many of the variables that affect RT, the RP does not seem to be affected by some factors that profoundly affect how quickly a person can generate a behavioral response to a stimulus. In the RT method, a subject is usually asked to press a key as quickly as possible when a target stimulus is presented. RT is the amount of time that elapses from target onset to response execution. Faster perception of a target stimulus is expected to decrease RT. Unfortunately for the study of perception, RT is also affected by non-perceptual factors. The subject's state of motor preparation is a critical factor. By increasing readiness to execute a motor response, a subject can decrease RT, at the expense of a higher error rate. To deal with conflicting instructions to respond as fast as possible and avoid errors, a subject ordinarily adopts a speed/accuracy tradeoff, decreasing readiness to respond enough to avoid making too many errors. The tradeoff can be affected by non-perceptual personality factors, such as the subject's propensity to take a cautious versus a more daring approach to the RT task (Rabbitt and Goward, 1994).

Non-perceptual factors that affect RT are problematic for interpreting RT data. A finding of longer RT for noisy than for non-noisy stimuli, for example, might indicate that more time was spent processing the noisy stimuli to make them perceptible. However, longer RT for noisy stimuli might also indicate that the subject had adopted different speed/accuracy tradeoffs for the two types of stimuli. Adding noise to stimuli would increase the likelihood of making errors. Subjects noticing the high error incidence are likely to decrease their readiness to respond to avoid making too many mistakes. Hence, a part of the RT difference could reasonably be attributed to a difference in state of motor preparation, rather than solely to a difference in stimulus processing time. In general, variation in the adoption of a speed/accuracy tradeoff makes it unsafe to conclude that a person who shows shorter RT than another person must also perceive the targets more rapidly.

In this study two groups of subjects were compared for their responsiveness to two different types of target stimuli, English words and Gestalt figures. The subjects in one group had more experience in reading English, so they were expected to perceive the English words faster and generate the RP earlier than the less experienced readers did. The Gestalt Figures were non-language stimuli (Rudell and Hu, 2000) with which neither group had greater experience. The absence of a priori reasons for a difference in perceptual powers for such stimuli suggested

that subjects in the two groups would perceive the Gestalt figures equally fast and therefore would show no significant difference in RP latency.

The behavioral results were expected to differ from the electrophysiological results, due to the operation of speed/accuracy tradeoff. The more experienced readers were expected to show shorter RT to English words than the less experienced readers did. However, the nature of the RT method suggested that the observed RT difference for words would partly be the consequence of a difference in speed/accuracy tradeoff, rather than solely the consequence of a difference in perception speed or the efficiency of stimulus processing. The less experienced readers were expected to miss more of the word targets and be more likely to erroneously respond to non-target images that they had mistaken for genuine words. This expectation could be verified by measuring target detection rates and error rates. The higher error rates expected for the less experienced readers of English were expected to generate greater pressure on them to alter speed/accuracy tradeoff in the direction of greater accuracy. Word targets and Gestalt figure targets were intermixed in an unpredictable order, so it was not possible for a subject to tailor different speed/accuracy tradeoffs for the two types of target. The pressure away from speed and toward greater accuracy would therefore affect responsiveness to the Gestalt Figures as well as responsiveness to the words. Thus, unlike the RP results, behavioral RT to the non-language targets was predicted to be longer for the less experienced readers of English than it was for the more experienced readers, despite there being no difference in how quickly they actually perceived the non-language targets.

2. Materials and methods

2.1 Participants

The participants were 36 adults who had all earned a college degree. Their mean age was 28.3 years (S.D. = 3.8). They had normal or corrected-to-normal vision, were right-handed, and had no history of neurological disease. They were recruited by local advertisement that offered payment for participating in the study. Informed consent was obtained from each subject. The research project received approval from the local Institutional Review Board.

Twelve of the subjects were in the Short-time Readers of English group. They were born and educated in the People's Republic of China. Half of them were females. Chinese was their primary language. They could speak, read, and write English, but they had received almost no exposure to that language before they were ten years old and only limited experience with it before reaching adulthood. They had moved from China to the USA and had resided there less than three years at the time that they participated in the study. The subjects in the Long-time Readers of English group were born and educated in the USA. Half of them were females. Their primary language was English. They could not read Chinese.

2.2 Stimulation

2.2.1 Rapid Stream Stimulation—The rapid stream stimulation technique was used to evoke the RP. This method greatly attenuates the P1 component and improves the quality of the RP signal (Rudell, 1992). In this method, a series of different images are successively displayed at a high rate on a computer monitor. Most of them are meaningless, non-recognizable images called background images. Occasionally, a recognizable image is interpolated in the image stream. It evokes the RP, unlike the non-recognizable images.

In this study, each image consisted of five characters, white-on-black. They were viewed from a distance of 120 cm. The images were all 1.14 degrees high by 3 degrees wide. Each image was displayed for 200 ms. The transitions from one image to another were immediate, so

successive images were displayed at a rate of 5/sec. Three types of images were displayed: (1) background images; (2) English words, and (3) Gestalt figures.

2.2.2 Background Images—An image stream contained mostly background images. They were designed to be unrecognizable and to have physical attributes that were similar to those of the target images. A background image consisted of five non-letter characters that were randomly selected from a set of 128, with the restriction that adjacent characters could not be the same. The random process and the large size of the character set produced an indefinitely large number of different background images. In Fig. 1 the image array at the top of the figure contains 14 background images and two target images.

2.2.3 English Word Targets—The word stimuli were 16 five-letter English words. They were chosen for their high frequency in printed literature, high degree of orthographic regularity, and low difficulty level. Their mean frequency in printed literature was 210/million (S.D. =160), based on the Kucera and Francis (1967) word tables. Each word occurred at least 50 times per million. The orthographic regularity of the words was indexed by the bigram positional frequency values given by Massaro, et al. (1980). This metric was derived from counts of the number of times a particular pair of letters occurred at a given position in words of a specified length. The mean of the natural logarithm of the count values was 7.23 (SD=.44), indicating that the words had highly regular orthographic properties. The mean difficulty level, based on the Rudell (1993) word difficulty ratings, was 1.22 S.D. below the mean difficulty rating that had been given to 870 words (S.D. = .027). This indicated that most people considered the words to be easy. The measurements of these three word properties make it likely that the subjects were familiar with all 16 words, the letter sequences in them, and their meanings. The word images are shown in the middle array of Fig. 1.

2.2.4 Gestalt Figure Targets—Sixteen non-word target images called Gestalt Figures were constructed. They are shown in the bottom array of Fig. 1. These images were designed to be recognizable in a stream of background images without perception of them being dependent upon prior experience with the English language. Their physical attributes were similar to those of the background images and the word images. They were called Gestalt figures because of the Gestalt law that a set of similar elements stands out as a figure in a background of dissimilar elements (Zusne, 1970). Each Gestalt figure consisted of the same non-letter character occupying each of the five character positions of an image. Like the five-letter words, Gestalt figures were readily perceived when they were interpolated in a stream of background images. Both types of target evoked the RP.

The Gestalt law can be demonstrated using elements that have familiar shapes, such as alphabetical characters, but that is not a necessary condition. The shapes of the foreground and background elements can be arbitrary and unfamiliar to the observer (Zusne, 1970).

A previous experiment used the RP to test whether familiarity with a repeated element affected how quickly a Gestalt figure was perceived (Rudell et al., 2000). One set of Gestalt figures was constructed from asymmetric capital letters displayed in their normal positions. A less familiar set was constructed from the same letters, but flipped left for right. Half of the background elements were also flipped left for right, so the physical attributes of the Gestalt figures did not make either set easier to perceive. In long-time readers of English, RP latency was 10.3 ms less for figures constructed from familiar, normally positioned letters than it was for figures constructed from the less familiar flipped letters. The difference was small but statistically significant. In contrast, RP latency in China-educated subjects was only 0.5 ms less for normal than for flipped letters, a negligibly small and statistically insignificant difference. The results suggested that great familiarity with an element in its normal position could reduce by a small amount the time needed for perception of a Gestalt figure in subjects

who had gained sufficient experience through long time reading of English. A similar effect was not detected in subjects who had lesser relevant experience, due to their having learned English later in life. In the present study, the Gestalt figures were constructed from elements that were unfamiliar to both groups of subjects, so there was no basis for predicting that either group would show shorter RP latency to them.

2.2.5 Sequence of images—The subjects detected targets during 16 viewing periods that lasted about 26 seconds each. Approximately 130 different images were presented during a viewing period, each image being displayed in the center of the computer screen for 200 ms. At least 10 of the first images of a viewing period were all background images. The rest of the viewing period consisted of 16 epochs, referred to as trials. By random process they were chosen to include either seven or eight images, so their durations were either 1.4 or 1.6 seconds. In eight of the epochs, the images were all background images, so no target was displayed. In the other eight epochs, all but one of the images was a background image. The exception was a target image, which was displayed for 200 ms, beginning 200 ms after the start of the epoch. The targets were word images for four of the target trials and Gestalt figures for the other four target trials. A random process determined the order in which word-target, Gestalt-target, and non-target trials occurred. The specific target that was displayed was also determined by a random process. When the 16 viewing periods were completed, each of the 16 word targets and each of the 16 Gestalt figure targets had been presented exactly four times. Thus, each subject was presented with 64 word-trials, 64 Gestalt-trials, and 128 non-target trials.

2.3 Perception of Targets in the Image Stream

The subjects were capable of detecting the great majority of the word and the Gestalt figure targets that were interpolated in the background image stream. In this type of stimulation the images are displayed in succession in the same place on the screen. For purposes of illustration, a related effect can be produced by examining the images shown in the top array of Fig. 1. This array contains a Gestalt figure target in the second row of the first column. It stands out from the background images because the same character is displayed at each of five positions. Detection of a Gestalt Figure does not depend on a person having familiarity with that particular character (Zusne, 1970). All that is needed to make it noticeable is the capacity to detect repetition of an arbitrary spatial pattern.

In contrast, detection of word targets does require previous experience with the characters used to construct them. The word WATCH (third row of the fourth column) stands out in the array because of a person's prior experience in reading English. In the absence of previous experience with its alphabetical components, the high similarity and high variability of physical attributes would make WATCH and other words virtually indistinguishable from the background images. Distinguishing words from background images is especially difficult when the images are displayed in swift succession, as they are in rapid stream stimulation. Early research with the rapid stream stimulation method (Rudell, 1992) showed that similarity of physical attributes prevented Arabic and Chinese words from being distinguished from background images in persons who could not read those languages. In contrast, China-educated subjects, who did have appropriate prior reading experience, readily detected the Chinese words.

2.4 Procedure

The subjects were given instructions on how to perform the detection task. They were shown examples of the background images, which they were supposed to ignore, and the word targets and Gestalt figure targets that called for a behavioral response. Use of a hand-held response device to indicate detection of a target was demonstrated for them. Lifting the index finger of the preferred hand unblocked a beam of light aimed at a phototransistor. This produced a voltage change that signaled to the computer that the subject had responded. To initiate a stream

of images, the subject pressed and released a button with the non-preferred hand. The image stream automatically stopped after about 26 seconds. By that time, an average of four English words and four Gestalt figures had been displayed in randomized order among approximately 130 background images. A minimum of 1.4 seconds separated successive target images.

The subjects were told that prizes would be awarded to the best performers. Both speed and accuracy counted. A subject received one point for each correct response that occurred between 300 and 800 ms after the onset of a target image. A bonus point was given if the response was rapid, less than 500 ms. A five-point penalty was imposed for responding when a target was not present or for responding prematurely to a target (RT less than 300 ms). Feedback on performance was displayed to the subject when the image stream stopped. The subjects were allowed to practice the detection task before beginning to compete for prize money. During competition, each of the 16 English words and each of the 16 Gestalt figures was presented four times, for a total of 128 target presentations.

2.5 Electrophysiological Recording

Brain wave responses were recorded from Ag/AgCl scalp electrodes using an electrode paste. A commercial skin preparation helped to reduce electrode impedance to less than 5 K-Ohms. Guidelines for using human event-related potentials to study cognition (Picton et al., 2000) were followed. The recording configuration included electrodes at Fz, Cz, Pz, and Oz, an electrode positioned caudal to theinion by 10% of theinion-nasion distance (Sub-Oz), and a supraorbital electrode for eye artifact detection. The ground electrode was placed on the left ear lobe. The right ear lobe was used as a common reference. The amplifier outputs were digitized at 320 Hz per channel.

Grand average monopolar responses recorded from sub-Oz, Oz, Pz, Cz, and Fz electrodes are shown at the top of Fig. 2. Mathematically derived waveforms are shown at the bottom. The bipolar waveform (Pz – Oz) was similar to RP responses obtained in previous studies. A similarly shaped composite RP response was mathematically derived from monopolar responses recorded from the sub-Oz, Oz, Pz, Cz, and Fz electrodes, weighted $-1/3$, $-2/3$, $1/3$, $1/3$, and $1/3$, respectively. None of these electrode sites was assumed to be inactive.

The onset of each analog-to-digital conversion epoch was synchronized with the onset of the first background image of an epoch. On target trials, the onset of the target image began 200 ms after the onset of the epoch. If eye artifact was detected anywhere in an epoch, the data for that trial were discarded. Trials were included in average waveforms whether the subject had made a behavioral response or not. Detection of artifact was the only basis for excluding trials. An average of 6.3% of the trials was rejected. The trial rejection rate was not significantly different for the two groups of subjects.

2.6 Data Analysis

The percentage of correct behavioral responses was calculated from the output of the phototransistor device. To be correct, a response had to occur between 300 and 800 ms after the onset of a target image. The great majority of the responses occurred in this time window, as is shown by the RT histogram in Fig. 3. For each subject, median RT values were calculated from the correct responses, separately for word targets and Gestalt figure targets. Error rates were calculated from responses that had erroneously been made during the non-target epochs.

The latency of the RP was calculated by measuring average waveforms from which a low amplitude driving rhythm had been removed. As observed in previous work (Rudell and Hua, 1996a), rapid stream stimulation generated a low amplitude driving rhythm that was time-locked to the image transitions. Its presence in the target trial waveforms was attenuated by

subtracting the average waveform for the non-target trials from the average waveform for the word trials and from the average waveform for the Gestalt trials. In both cases a mathematical method was used to derive a composite RP response from monopolar responses that were recorded from the sub-Oz, Oz, Pz, Cz, and Fz electrodes, using weightings of $-1/3$, $-2/3$, $1/3$, $1/3$, and $1/3$, respectively. Measurements made for the statistical analyses reported here were obtained from the composite RP response. It was preferred to the bipolar derivation because it appeared to be less sensitive to individual difference in scalp distribution. Measurements from both derivations, however, yielded fundamentally the same results.

RP latency was calculated from composite waveforms using a previously described computer algorithm (Rudell and Hua, 1997). The amplitude of the RP was measured from them by finding the most positive value in the time window 175 to 375 ms after target image onset (Fig. 3). For each subject, therefore, measurements of RP latency and amplitude were separately obtained for the word trials and for the Gestalt figure trials.

Dependent variables were submitted to analyses of variance (ANOVA) that had between-subject and within-subject factors. Between-group differences were assessed by comparing observations for the Short-time Readers of English group with observations for the Long-time Readers of English group. The number of responses made during non-target trials was used to assess the rate at which the subjects made errors. Detection rates, behavioral RT, RP latency, and RP amplitude were separately analyzed for word trials and Gestalt trials. Comparison of observations for word trials with observations for Gestalt trials was a within-subject factor. Violation of the sphericity assumption was not a problem, because there were only two levels for each factor (Vasey and Thayer, 1987).

The effect of perceptual experience on stimulus processing ability was assessed by comparing responses to stimuli with which the two groups of subjects differed in amount of prior experience (i.e., the word targets) with responses to stimuli for which the groups did not differ in amount of prior experience (i.e., the Gestalt figure targets). Behavioral and electrophysiological indicators of stimulus processing were separately examined by computing the target type by group interaction for each of four measures, detection rate, behavioral RT, RP latency, and RP amplitude. Subjects in the USA-educated group were hypothesized to be better equipped than subjects in the China-educated group to perceive the English words, relative to their ability to perceive the Gestalt targets. That effect would be manifested by a target type by group interaction. The strength of the relationship was evaluated by calculating the statistic Eta-Squared. It indicates the proportion of total variability in the dependent variable that is accounted for by variation in the independent variable. High values of Eta-Squared indicate robust experimental effects.

Theoretically, due to their having more thoroughly developed neural processes that facilitate word perception, long-time readers of English would perceive the word targets more quickly than the short-time readers did. The latency of the RP theoretically reflects the speed of perceptual processing of recognizable images, so the long-time readers were expected to show significantly shorter RP latency for the word targets than the short-time readers did. There was no a priori basis for deciding whether the USA-educated or the China-educated subjects would be better equipped for perceiving the Gestalt figures. Therefore, it was hypothesized that the two groups would not differ significantly in RP latency to the Gestalt Figure targets.

A different result was predicted for the behavioral reaction time variable. The China-educated subjects were expected to be more likely to make mistakes in detecting the English words, because they had less English reading experience than the USA-educated subjects did. A high error rate would produce pressure on them to move their speed/accuracy tradeoff toward greater accuracy at the expense of lower speed. The unpredictable order of Word and Gestalt trials

would prevent them from adopting different speed/accuracy tradeoffs for word and Gestalt targets. Therefore, it was hypothesized that the short time readers of English would have significantly longer RT not only to words, but also to the Gestalt Figure targets.

2. Results

3.1 Behavioral Data

3.1.1 Overall Behavioral Performance—Most of the targets were detected and few errors were made. The RT histogram in Fig. 3 illustrates this result. It was computed for all target presentations and all subjects. Behavioral responses were generated between 300 and 800 ms after target onset on 4226 of the 4,608 target presentations, a 91.7% hit rate. Very few responses were made during the 500 ms interval that preceded the correct response window. From 200 ms before target onset to 300 ms after target onset, 45 responses were generated at varied times. These responses were errors because they either occurred before a target had been presented or they were made in the premature response window, 0 to 300 ms after target onset. The error rate was 1%, about the same as the error rate that was observed for the non-target trials.

3.1.2 Detection Rates and Error Rates—The two subject groups differed significantly in the percentage of targets that they detected. Table 1 lists mean behavioral response rates for word targets, Gestalt targets, and non-targets for each group. It also gives F-values and p-values for between-subject ANOVA tests that compared the groups on these measures.

The greatest difference was observed for response rates to the word targets. Subjects born in the USA detected 98.4% of the words. The subjects recently from China detected only 86.3% of the words. Statistically, the difference was highly significant. For Gestalt targets the group difference was in the same direction, but it was smaller (90.8% versus 84.9%). ANOVA confirmed that this difference, though less robust than the effect for word trials, was nonetheless a statistically significant effect.

The subject groups also differed significantly in the percentage of errors that they committed. The rates of erroneous responding on non-target trials were higher for the subjects recently from China (2.0%) than they were for the subjects born in the USA (0.5%). Both error rates were very low. Nonetheless, the difference in error rate for the two groups of subject was a highly significant effect.

The word targets were detected at a higher rate than the Gestalt targets. Within-subject ANOVA indicated that the difference was statistically significant ($F(1, 34) = 11.92, p = .002$). The target type by group interaction was also statistically significant ($F(1, 34) = 5.57, p = .024$). This result was due to the word-Gestalt detection difference being greater for the subjects born in the USA (7.6%) than it was for the subjects recently from China (1.4%).

3.1.3 Reaction Times—The subjects born in the USA had shorter RT than the subjects recently from China, whether the targets were words or Gestalt figures (Table 2). The group difference in RT was 86 ms for word targets and 36 ms for Gestalt targets. ANOVA showed that both differences were statistically significant.

Subjects born in the USA had 16 ms shorter RT for word targets than for Gestalt Targets. In contrast, subjects recently from China took 34 ms longer to respond to the words than to the Gestalt targets. The oppositely directed RT differences for the two target types produced a very robust effect, as indicated by the highly significant target type by group interaction ($F(1, 34) = 69.47, p < .0001$).

To summarize the behavioral data, statistical analysis indicated a higher level of behavioral performance for subjects born in the USA than for subjects recently from China. The subjects born in the USA detected more of the targets, responded more rapidly to them, and made fewer errors. The performance differences were more pronounced for the word targets than for the Gestalt targets, but they were clearly evident for both types of target.

3.2 Electrophysiological Results

3.2.1 Average waveforms—The grand average waveforms for word trials and for Gestalt figure trials that were computed for the USA-Educated readers of English are shown in Fig. 4. The analogous waveforms for the China-Educated subjects are shown in Fig. 5. Inspection of the figures shows that for USA-Educated subjects RP latency was less for words than it was for Gestalt figures. The opposite effect was observed for the China-Educated subjects. For them, RP latency was substantially longer for words than it was for Gestalt figures. As described below, ANOVA confirmed the statistical significance of several between-subject and within-subject factors, but it found no significant difference for some factors that had significantly affected behavioral measures.

3.2.2 RP Latency—The latency of the RP to word targets was less for subjects born in the USA (271.5 ms) than it was for subjects recently from China (310.7). Table 3 shows that the approximately 40 ms difference in latency was a highly significant effect ($p < .0001$). In contrast, the latency of the RP to Gestalt targets was nearly identical for the two groups. The latency difference was less than one ms. It did not approach statistical significance ($p = .907$).

Within subject ANOVA showed that RP latency was significantly longer for word targets than for Gestalt targets ($F(1, 34) = 54.26, p < .0001$). However, this effect was entirely due to the subjects recently from China, whose RP latency to word targets was about 33 ms longer than it was for Gestalt targets. For subjects born in the USA, the difference was in the opposite direction, RP latency being about 5 ms less to word targets than it was to Gestalt targets. This small difference was statistically significant ($p < .01$). The oppositely directed differences resulted in a target type by group interaction that was very highly significant ($F(1, 34) = 100.56, p < .0001$).

3.2.3 RP Amplitude—The amplitude of the RP to word targets was greater for subjects born in the USA than it was for subjects recently from China (Table 4). The difference was statistically significant ($p = .002$). For Gestalt targets, however, the group difference in RP amplitude was negligibly small. It did not approach statistical significance ($p = .435$).

Within-subject ANOVA showed that RP amplitude was significantly greater for word targets than for Gestalt targets ($F(1, 34) = 9.28, p = .004$). This effect was restricted to the subjects born in the USA. For subjects recently from China, RP amplitude was instead slightly greater for Gestalt targets than for word targets. This resulted in a statistically significant target type by group interaction ($F(1, 34) = 15.95, p < .001$).

To summarize the electrophysiological data, statistical analysis indicated faster RP responses for subjects born in the USA than for subjects recently from China if the targets were words, but no group difference in RP latency if the targets were Gestalt figures. The latency effects were paralleled by statistically significant but less robust amplitude effects. The two groups did not differ significantly in RP amplitude for Gestalt targets, but the USA-educated subjects generated larger responses than the China-educated subjects when the targets were words.

3.3 Sensitivity of Behavioral and Electrophysiological Measures

The effect of long-time perceptual experience on stimulus processing ability was examined by comparing responses to word targets with responses to Gestalt targets for USA vs. China educated subjects. An effect was identified by a significant target type by group interaction. The strength of the relationship was indicated by the Eta-Squared statistic. The results for behavioral and electrophysiological dependent variables are given in table 5, ranked by the magnitude of the Eta-Squared values that were obtained.

RP latency showed the most robust effect. The Eta-Squared value calculated for it was .75, so the independent variable accounted for three-fourths of the RP latency variability. The Eta-Squared value for RT was smaller (.67), so the independent variable accounted for a smaller proportion of the behavioral variability, approximately two-thirds of it. The less robust relationship for the behavioral measure was partly due to the USA-educated subjects having significantly shorter RT than China-educated subjects not only for the word targets, but also, to a lesser extent, for Gestalt targets. RP latency, in contrast, showed a large between-group difference for word targets, but no difference for Gestalt targets.

RP amplitude and detection rate measures yielded less robust effects. The independent variable accounted for only one-third of the variability of RP amplitude and only one-seventh of the detection rate variability. Thus, RP latency was the most powerful indicator of a group difference in the processing of word targets versus non-language targets.

Fig. 6 illustrates the fundamentally different influence that between-subject factors had on behavioral RT versus RP latency. The RT data shows that USA-educated subjects responded faster than the China-educated subjects, whether the targets were words or Gestalt figures. The error bars in the figure, which indicate one standard error of the mean, show that the effect was robust for both types of target. The RP latency data, in contrast, showed that USA-educated subjects responded faster than China-educated subjects only if the targets were English words. The effect was very robust, even more powerful than the effect on RT, as indicated by the smaller standard errors of the mean for RP latency. For Gestalt figure targets, the RP data indicated that USA-Educated subjects did not respond faster than China-Educated subjects. The standard errors of the mean were similar to the ones observed for the word trials, so the failure to detect a difference was due to the group difference in RP latency to Gestalt figures being minute, rather than insufficient statistical power.

4. Discussion

Previous study showed a high correlation between RP latency and reading ability, as measured by performance on the verbal portion of the Graduate Record Exam (Rudell and Hua, 1997). That relationship could be explained by supposing that the higher scorers had done more reading than the lower scorers did. A greater amount of reading would have given greater exposure to a larger set of words, thereby enabling higher performance on the verbal test. Theoretically, more time spent in reading would also have fostered the development of neural processes that facilitated the perception of words and shortened RP latency. Therefore, persons who showed shorter latency RP to words would be expected to perform better on the verbal test than persons who showed longer latency RP, as was observed.

Correlation findings may be suggestive, but they are open to multiple interpretations. Investigators of the role of the magnocellular system in reading dysfunction recognized this problem (Galaburda and Livingstone, 1993; Evans et al., 1994; Demb et al., 1998). They warned that the observation of smaller neurons in poorer readers might only be a marker for reading problems that was associated with a different factor that was more directly related to dyslexia. Smaller neurons might process and transmit information more slowly than normal

neurons. If so, an alternative interpretation of the relationship of RP latency to performance on the verbal test is that longer RP latency resulted from the operation of smaller, more slowly responding neurons, which were more likely to be found in subjects who had performed poorly on the test, but they were only associated with another factor that was more directly related to the reading skill that a person possessed. Other possible interpretations of the correlation results were discussed in Rudell and Hua (1997). To provide support for the contention that years of reading experience build up neural processes that specifically facilitate the perception of words in the language that is read, it was necessary to carry out further research that could decrease the likelihood of alternative interpretations of the relationship of the RP to reading ability.

It was not feasible to conduct a genuine experiment in which persons were randomly assigned to do specified amounts of reading in English. Years are needed to convert reading from a struggling activity to an effortless task. Instead, advantage was taken of a natural experiment that resulted in people having differing amounts of English reading experience. Long time residence in China prior to arrival in the U.S.A. was the reason that the subjects of one group had less English reading experience than the subjects of the other group did. This basis for forming experimental groups differed importantly from classifications based on performance on a written test. There is reason to be concerned that persons who perform poorly on a reading test are more likely to have associated deficiencies, such as smaller neurons in the magnocellular system, than would persons who had scored higher on the test. In contrast, there was little reason for supposing that the China-educated and the USA-educated subjects would differ in the likelihood of their having such physiological deficiencies. This alleviated, but did not remove, concern that observed differences in RP latency to English words might be the consequence of something other than the amount of English reading experience that a person had acquired.

The two groups did not differ solely in the amount of experience that they had in reading English. Age, sex, and education level were equated, but it was not possible to balance every variable that conceivably could be associated with a person having or not having lived in China. Differences in diet, for example, might have affected the size of neurons or how rapidly they could propagate action potentials. Environmental and cultural difference might also have existed that potentially could affect how quickly images evoked the RP. Therefore, control stimuli were included in the image stream to allow assessment of the possibility that such factors were responsible for producing a difference in RP latency. The subjects in the two experimental groups differed in the amount of experience that they had in reading English, but they did not differ in the amount of experience that they had with the Gestalt figures.

The latency of the RP for the Gestalt figures was nearly identical for the two groups of subjects. This result indicated that any group differences that were not controlled, including dietary, environmental, and cultural factors, had negligible effects on the latency of the RP to Gestalt figures. In contrast, there was a robust group difference in RP latency to the English word stimuli. The specificity of the effect to English words provided supporting evidence that long-time reading experience is a causal determinant of the latency of the RP to words. It reinforced the idea that fast acting neural processes specific to the language that a person has learned to read are developed through reading and they continue to develop into more efficient facilitators of perception even after a person has been reading a language for several years. The difference in RP latency to words observed for the two groups showed that the number of years of English reading experience that the China-educated subjects had acquired was not sufficient to develop processes in them that matched in efficiency the ones that had developed in the USA-educated subjects. The putative neural processes are thought to operate automatically on words in the appropriate language, becoming faster acting and more autonomous as years of reading experience increase. They must operate rapidly, at least by the time that the RP is evoked.

Short latency seems to be one of the factors that make the RP well suited for studying increases in the speed of visual processing that develop through longtime reading experience. The small amount of time needed for generation of the RP indicates that it must be a relatively direct reflection of neural processes that mediate visual perception. Other indexes of perception that have longer latency are less direct reflections of perceptual processing. Their longer latency makes them potentially vulnerable to the influences of a variety of non-perceptual factors. Variability induced by non-perceptual factors can obscure significant differences in the speed of perceptual processing or even make them impossible to detect.

A cerebral blood flow experiment that investigated language processing in Chinese-English bilinguals provides an example. Event-related fMRI showed no significant difference in hemodynamic response curves for Chinese versus English verb generation tasks (Pu et al., 2001). The subjects had much more experience with Chinese than with English, so they should have processed the Chinese words more rapidly than the English words. However, the changes in cerebral blood flow had very long latent periods, because they were reflexively evoked in response to altered metabolic demand. No significant change in blood flow occurred during the first three seconds after word onset. The hemodynamic response reached a peak at a latency of about eight seconds. The standard deviation of the peak latency difference for Chinese versus English words was more than one second. This high variability precluded the possibility of detecting latency differences similar to the ones that have been detected for the RP. A study that examined Chinese-English bilinguals, for example, showed that the RP had significantly shorter latency for words in their first language (Chinese) than it did for words in their second language (Rudell and Hua, 1996a). In the present study, the latency of the RP for English words was about 40 ms less for subjects whose first language was English than it was for subjects who had acquired English as a second language. Statistically, this difference was a highly significant effect, due to the low variability of the RP latency measure.

Behavioral responses in a reaction time task occur much faster than changes in cerebral blood flow, so potentially they could have greater power to detect differences in the speed at which words are perceived. However, behavioral responses do not solely reflect the speed of perceptual processing. A number of factors that exhibit non-perceptual influences on RT are well known since the early studies of F. C. Donders (1868/1969). Included among them are the subject's age, amount of training on the task, fatigue, S-R compatibility, and the presentation of a warning stimulus.

Considerable evidence indicates that the rapidly generated RP is not sensitive to many of the non-perceptual factors that affect behavioral RT, probably because of its short latency. The RP is elicited by the display of a word well before a person can make a behavioral response to it, even in the simplest RT task. Unlike the case for RT, the subject does not have to be told to generate the RP. It is automatically elicited if the subject has the requisite perceptual skill. No decision has to be made about how to respond, so the RP is unlikely to be affected by factors like the Simon Effect (Simon and Rudell, 1967; Simon, 1990) in which incompatibility of the stimulus and the response produces an increase in RT. The presentation of a warning signal that produced a typical decrease in behavioral RT did not alter the latency of the RP (Rudell and Hu, 2001). In contrast, a warning signal significantly decreased the latency of electrophysiological responses that were generated at longer latency than the RP. These results suggested that the short latency of the RP prevented it from being affected by a non-perceptual factor, motor preparatory responses that were elicited by the presentation of a warning signal.

Donders described the non-perceptual effect of speed/accuracy tradeoff on RT. He noted that the tensing of muscles speeded reactions but doing this often produced erroneous anticipatory responses. A variety of factors can influence the particular compromise between speed and accuracy that a person adopts. An essential element is information that the subject receives

about errors that have been made. In the active tracking model of Rabbitt and Goward (1994), people do not automatically know how fast they can make accurate responses. Instead, they learn how fast they can respond without making mistakes by going increasingly fast until they make errors. Then they slow down to avoid risky RT bands within which the probability of errors is unacceptably high.

When comparing one group of subjects with another, the degree of caution and the level of motivation of the subjects are some factors that affect how quickly behavioral responses are generated. These non-perceptual factors, however, seem not to be the only reasons that the relationship between IQ test scores and RT is typically modest (Rabbitt and Goward, 1994). People also differ in the sensitivity with which they can monitor the limits of their own performance. Some may be better equipped than others to cope with the complexity of a reaction time task. The operation of these and other non-perceptual factors seems to contribute to the weakness of the relationship of RT to mental ability.

The design of the present study should have produced a group difference in speed/accuracy tradeoff, if the less experienced readers of English had greater difficulty perceiving the English words than the more experienced readers did. The results indicated that this was the case. The China-born subjects missed a significantly higher percentage of the targets, especially the word targets. They were also more likely to incorrectly make behavioral responses when no target was present. Probably their error rates would have been even higher, had they not inhibited their readiness to respond to prevent themselves from erroneously making a response when no target was present.

An inducement to decrease readiness to respond would be provided by a subject's awareness of the commission of errors and the penalty it entailed. Because they committed more errors than the USA-born subjects did, the China-born subjects received more warnings to be careful. In contrast, the USA-born subjects had longer runs of error-free trials. This should have promoted a more daring type of motor preparation that enabled more rapid generation of behavioral responses on subsequent trials. Random intermixing of target types prevented a subject from knowing which type of stimulus would be presented next, so a subject's readiness to respond would affect behavioral reactions to the Gestalt figure targets as well as the word targets. For this reason, the China-born subjects would be expected to show longer RT for the Gestalt figure targets than the USA-born subjects did, even if the speed of processing these targets was equivalent for the two groups. In addition, the group RT difference observed for words almost certainly reflected in part the effect of a difference in speed/accuracy tradeoff as well as a difference in the speed of perceptual processing of the words.

The RP results provided evidence that the less experienced readers of English perceived the Gestalt figures just as rapidly as the more experienced readers of English did. Unlike the case for word stimuli, the group difference in RP latency for the Gestalt figures was insignificant, less than one millisecond. Statistical power was available to detect a difference in RP latency that was far smaller than the RT difference observed for the Gestalt targets. The best explanation for these findings is that the RP was affected by the speed of image processing, but it was not affected by speed/accuracy tradeoff.

Short latency and freedom from the influence of non-perceptual factors seem to contribute to the low variability of RP latency and give it advantages for studying the speed of perceptual processing. In the Rudell and Hua (1997) study, RP latency to words was a better predictor of performance on the verbal portion of the Graduate Record Exam than behavioral RT or longer latency electrophysiological responses were. In the present study, the Eta-Squared statistic showed that RP latency had a more robust relationship to amount of English reading experience than RT did. This result provided additional support for the contention that RP latency generally

shows a stronger relationship to image processing speed than RT does, because it is not affected by non-perceptual variables that affect RT (Rudell and Hu, 2001).

The results supplied less conclusive evidence on the particular aspects of image processing that the RP reflects. Some studies have implicated the processing of semantic properties of words as a determinant of RP responses (Hinojosa et al., 2001a, 2001b, 2001c, 2001d; Martín-Loeches et al., 1999, 2001a, 2001b). The issue is controversial (Pu et al, 2005; Martín-Loeches, 2007; Zhang et al., 2008). Determining the specific aspects of words that affect the generation of the RP is not a simple matter. One problem is that the categorization of words into experimental groups based on one criterion may also segregate them on other aspects that have a more direct influence on generation of the RP. Words in the Rudell and Hua (1997) study were categorized on the basis of word difficulty, which was defined by ratings of the level of intellectual development needed to comprehend them. Longer RP latency was observed for the more difficult words. The easy and hard words did not differ significantly in two measures of orthographic regularity or in the frequency with which they appeared in printed literature. This made it unlikely that these non-semantic properties of the words were the source of the RP latency difference. Nonetheless, the results did not constitute unchallengeable evidence for a semantic influence on the RP elicited by words, because other associated non-semantic properties of the words that were not measured could possibly have been responsible for the observed latency difference. If semantic factors do affect generation of the RP, they must operate rapidly, at least by the time that the RP is generated. The present study did not resolve the question of whether the RP reflects the processing of semantic aspects of words. However, the RP responses to Gestalt figures in this study did show, in confirmation of previous work (Rudell and Hu, 1999; Rudell and Hu, 2000; Rudell et al., 2000), that the RP can be evoked by visual images that are devoid of the semantic properties that characterize words.

An anonymous reviewer pointed out the likelihood that the RP has often been generated in other experiments without its having been recognized as such by the investigators who conducted the experiments. One example was a negative potential described by Junghöfer and colleagues (Junghöfer et al., 2001; Herbert et al., 2008). Another potential that had the same latency and topography as the RP was the N2pc component (Luck and Hillyard, 1994; Eimer, 1996; Wascher and Wauschkuhn, 1996; Dell'Acqua et al. 2007). The posterior N2-type component measured in RSVP tasks (Koivisto and Revonsuo, 2008; Kranczioch et al., 2007; Sergent et al., 2005) was also considered to be similar to the RP.

The reviewer was probably correct in supposing that the RP is often elicited in electrophysiological experiments. The robust RP responses recorded for Spanish language stimuli from subjects living in Spain and for Chinese language stimuli from subjects living in China show the generality of the phenomenon for different types of language stimuli. Non-language stimuli, including pictures, faces, and Gestalt figures, can also evoke the RP. This suggests that the RP reflects a fundamental physiological process that generally operates in support of visual perception. The RP response can be affected by prior relevant reading experience, as the present study shows, but it is not restricted to language stimuli.

The rapid stream stimulation method is usually used in most laboratories doing RP Research, but it is not essential for evoking the RP. In early RP studies, prior to the development of the preempt stimulus technique and later the rapid stream stimulation method, the RP was observed using traditional methods of stimulation (Rudell, 1991). The virtue of these stimulation techniques lies in their capacity to disentangle the RP from other activity that is time-locked to stimulus presentation. When comparing responses to two different types of stimuli, the investigator must be wary of differences in the physical attributes of the stimuli, such as image size, location in the visual fields, and others, because potentials related to those aspects of

stimulation can be confounded with the recognition potential, as has previously been demonstrated (Rudell, 1991).

In traditional methods of stimulation, virtually any abruptly displayed image evokes a short latency component. Its latency can be as little as 100 ms for very bright stimuli, but it becomes markedly longer in latency for less intense stimuli. Image size and position in the visual fields also affect it (Rudell, 1991). The early response may be labeled P1 or N1, depending on its polarity. A change in the position of the stimulus in the visual fields can reverse the polarity of the early response. For example, it may be positive for upper visual field stimulation, but negative for lower field stimulation (Michael and Halliday, 1971; Jeffreys and Axford, 1972; Jeffreys and Smith, 1979).

Unlike the RP, the early response did not distinguish recognizable from non-recognizable images. Identical responses were obtained for word images and meaningless control images if they shared similar physical attributes (Rudell, 1991; Rudell et al., 1993). This made the early response unsuitable for measuring differences in speed of perception like those expected for words that differed in frequency, familiarity, or difficulty (Rudell and Hua, 1997). The development of the rapid stream stimulation technique (Rudell, 1992) was a big advance for RP research. It greatly attenuated the early response and helped to isolate the RP from electrical activity that otherwise would have tended to obscure or distort it.

The reviewer noted that the effects of lexical stimulus parameters on potentials that occurred even earlier than the RP have been investigated. In particular, Xue et al. (2008) presented several different types of language stimuli to Chinese-English bilingual subjects while recording electrophysiological responses. The subjects made behavioral responses to picture stimuli, but these trials were discarded and no reaction time data were collected. N1 and P1 responses were recorded that had latencies of 150 to 170 ms. The most negative potentials, relative to an average reference, were observed for electrodes positioned over the occipitotemporal lobe. Only the amplitude of N1 responses recorded from PO5 and PO6 electrodes were analyzed. N1 latencies and P1 responses were not examined.

The early response showed no effect of lexicality. N1 amplitude did not differ significantly for Chinese words versus Chinese non-words or for English words (e.g. sky) versus consonant strings (e.g., xnr). Inspection of figures 3 and 4 in the Xue et al. (2008) study shows that there were also no effects of lexicality on the latency of the N1 response. In addition, no significant N1 differences were found when Chinese words were compared with English words.

In contrast to these negative findings for word stimuli, a significant effect was found for single letter stimuli. N1 amplitude was larger for a letter in the Roman alphabet than it was for a letter that was unfamiliar to the subjects. A smaller difference was found for a familiar logographic Chinese character versus an unfamiliar logographic character. The difference was statistically significant for short duration (100 ms) presentations of the stimulus, but not for long duration (750 ms) presentations. Modulation of N1 by visual, linguistic, and task factors produced a complex pattern of N1 sensitivity that led the authors to argue that the connection between enhanced N1 amplitude and visual expertise was questionable.

The results of the Xue et al. (2008) study were consistent with previous research in showing that N1 and RP responses differ not only in latency but also in the factors to which they are sensitive. Unlike the RP, N1 did not differ for words versus non-words. Neither was a difference observed for words in a familiar versus a less familiar language. RP studies, in contrast, showed significantly longer latencies for words in a second language than in a primary language (Rudell et al., 1996a). If a person lacked familiarity with a language, no response was evoked and the electrophysiological record was indistinguishable from meaningless control stimuli (Rudell, 1992). This indicates that the RP and the N1 response are completely different phenomena.

A critical aspect of our study was the ability to test the hypothesis that behavioral reaction time is influenced by multiple non-perceptual factors to which the RP is invulnerable. That hypothesis was not tested in the Xue et al., 2008 study. No differences in N1 latency were observed that could be compared with corresponding differences in behavioral RT. In contrast, the approximately 40 ms shorter RP latency observed for subjects who had long-term experience reading English relative to less experienced readers of English was a robust and exciting finding. It opened a prospect for research that is not available for N1, which showed no latency differences, or for components that have longer latency than the RP, which, like behavioral RT, show latency changes that are affected by non-perceptual factors (Rudell and Hu, 2001).

Despite not resolving all issues concerning the nature of the RP, it is believed that the results described in this study are important. They encourage use of the RP for investigating the acquisition of reading ability. Students and educators put forth enormous efforts to develop high levels of reading skill. A tool that could detect progress in the formation of acquired neural processes that facilitate the perception of words and is free from the influences of non-perceptual factors that affect other indexes of word perception would be highly valuable for investigating their development. The results of this study supported the idea that the RP could be that tool. They transcended previous correlation findings by demonstrating a causal effect of long-time reading experience on RP latency that was specific to the language that a person had learned to read. They showed that the RP was not affected by the speed/accuracy tradeoff that influenced behavioral RT. They showed that the latency of the RP had a stronger relationship to the amount of relevant reading experience that a person had than did behavioral RT. These findings, in conjunction with other studies demonstrating the ability to measure the RP for rates of word presentation that are too fast for behavioral responding (Rudell, 1999) and the capacity of the RP to reveal the processing of words when behavioral measures give no indication of it (Rudell and Hu, 2000), suggest the potential value of the RP for investigating in the classroom the development of neural processes that facilitate skilled reading.

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Fig. 1.

Background and target images. The array of images at the top (A) contains 14 background images, one Gestalt figure target, and one English word target. The middle array (B) contains the 16 word targets. The bottom array (C) contains the 16 Gestalt targets. The images are black on white in this figure, but they were white on black when displayed on the computer monitor.

Fig. 2.

Monopolar recordings and derived waveforms. The electrical responses shown in this figure are grand averages computed for all Word and Gestalt target stimuli and all subjects. Monopolar average waveforms recorded from electrodes placed at Fz, Cz, Pz, Oz, and Sub-Oz locations are shown at the top of the figure. An electrode on the right ear lobe served as a common reference. The bottom of the figure shows two waveforms that were derived from the monopolar recordings. A bipolar waveform was obtained by calculating the Pz – Oz difference. Neither electrode site was assumed to be inactive. The RP, as measured in previous studies, is the initial downward deflection of the Pz – Oz waveform. It indicates that the Oz electrode is becoming more positive relative to the Pz electrode or equivalently that the Pz electrode is becoming more negative relative to the Oz electrode. The other derivation was a composite waveform that was calculated from the five monopolar recordings, applying specified weights to each. The composite derivation was used for data analyses and for plotting waveforms in other figures. The 2 μ V calibration marker applies to all waveforms in the figure.

Fig. 3.

The RT histogram and the grand average recognition potential computed for all Word and Gestalt target trials and all subjects. The vertical lines at time zero indicate the onset of a 200 ms duration target image. The time window used to define a correct behavioral response and the time window used for measuring the RP are indicated.

USA-Educated Readers

Fig. 4.

The recognition potential for USA-Educated readers of English. The line passing through the most positive value of the word target average waveform and the most positive value of the Gestalt target average waveform indicates that in these subjects RP latency was slightly less for English words than it was for Gestalt figures.

China-Educated Readers

Fig. 5.

The recognition potential for China-Educated readers of English. The line passing through the most positive value of the word target average waveform and the most positive value of the Gestalt target average waveform indicates that in these subjects RP latency was substantially longer for English words than it was for Gestalt figures.

Fig. 6. Behavioral reaction time versus recognition potential latency. The error bars indicate one standard error of the mean.

Table 1

Mean Behavioral Response Rates (%).

	USA-Educated	China-Educated	$F_{1,34}$	p
Word Targets (correct responses)	98.4	86.3	50.32	.000
Gestalt Targets (correct responses)	90.8	84.9	5.83	.021
Non-Targets (errors)	0.5	2.0	16.05	.000

Table 2

Mean Reaction Times (ms).

	USA-Educated	China-Educated	$F_{1,34}$	p
Word Targets	449	535	58.05	.000
Gestalt Targets	465	501	10.74	.002

Table 3

Mean RP Latency (ms).

	USA-Educated	China-Educated	$F_{1,34}$	p
Word Targets	271.5	310.7	59.85	.000
Gestalt Targets	276.6	277.3	0.01	.907

Table 4Mean RP Amplitude (μV).

	USA-Educated	China-Educated	$F_{1,34}$	p
Word Targets	3.21	2.12	11.13	.002
Gestalt Targets	2.46	2.23	0.63	.435

Table 5

Strength of Relationship.

Measure	$F_{1, 34}$	Eta-Squared
RP Latency	100.56	.75
Behavioral RT	69.47	.67
RP Amplitude	15.95	.32
Detection rate	5.57	.14