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Cognitive Brain Research 25 (2005) 273 – 282

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Research Report

The recognition potential: Semantic processing or the detection of differences between stimuli?

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Accepted 6 June 2005
Available online 20 July 2005

Abstract

The recognition potential is traditionally described as an electrical index elicited when subjects view a recognizable stimulus. Recent studies further show that it may be influenced by semantic processing. In this study, we investigated whether this observed influence is really produced by differences in semantic processing or whether it might be caused by the detection of differences between sequentially presented stimuli. In two different experiments, we systematically altered the type of background images presented while keeping the recognizable word constant. Analyses revealed that the same recognizable words elicited an RP with different amplitudes and latencies when viewed under different background conditions. Control stimuli, which were identical to background stimuli, did not elicit the RP. Hence, we postulate that when using the rapid stream stimulation paradigm, RP might also be influenced by the detection of differences between sequentially input stimuli. It is necessary to clarify whether RP changes are caused by the processing of the stimuli or by the detection of difference between successively input stimuli before any conclusion could be made.

Theme: Neural basis of behavior
Topic: Cognition

Keywords: Recognition potential; Semantic processing; Detection of difference; Chinese visual stimuli; Event-related potential

1. Introduction

The recognition potential (RP) is an electrical brain response that peaks between 200 and 250 ms after subjects view a recognizable visual stimulus—such as words, pictures, or faces—as opposed to meaningless images [7,16,22,27]. Although some physical attributes such as image quality [25] may affect the RP, it has been suggested that the crucial factor for generating the RP is image recognition [22,27]. Further study (e.g., [27]) indicated that the RP may reflect semantic or conceptual processing as well. This assertion was supported by experiments performed by Martín-Loeches and colleagues [16,18] in which words, pseudowords, strings of letters, and word fragments were presented to subjects. RP amplitude significantly increased in parallel to the level of reading-related processing. Specifically, from strings of letters, pseudowords, to words, the RP amplitude increased gradually. It was concluded that the RP (a) does not reflect an all-or-none process but, rather, a gradual response to the different steps of the reading process, and (b) its amplitude is proportional to the level of information available in the stimulus [16,18]. Moreover, in other experiments, the RP appeared to be affected by semantic categories (such as concrete vs. abstract words [17], words vs. pictures [7], animals vs. tools [9], and open- vs. closed-class words [8]). Based on its sensitivity to semantic processing and its short peak latency compared with other ERP components related to such

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doi:10.1016/j.cogbrainres.2005.06.001

processing (e.g., N400), it was concluded that the RP is sensitive not only to the presence of semantic processing but also to specific semantic content. Thus, the RP has been considered an important measure when investigating mechanisms associated with early semantic processing [10,18].

Although the utility of the RP in studying semantic processing seems promising, the authors of the present research postulated that in addition to semantic processing, the special stimulus presentation paradigms used in prior RP research ("preempt stimulus technique" and "rapid stream stimulation") may also influence the RP. The preempt stimulus technique and rapid stream stimulation were originally introduced by Rudell [22] to isolate the RP from other evoked activity. There are three important characteristics of these paradigms. First, there are two types of stimuli—meaningless background stimuli and meaningful experimental stimuli. Second, the background stimuli are always presented between the experimental stimuli. Third, stimuli are presented rapidly with very short or zero interstimulus intervals (ISIs). The role of the background stimuli is to temporally usurp activity in the visual afferent pathway. For example, the visual-related components (e.g., N1–P2 complex) elicited by the experimental stimulus (following background stimuli) are reduced. If the experimental stimulus is meaningful to subjects, then it would be easier to detect the RP elicited by it because the contamination from other visual-related components had been reduced. Moreover, a better RP signal is produced by separating experimental stimuli using background stimuli because components elicited by meaningful stimuli are unable to overlap with one another.

Despite the advantages of using the preempt stimulus technique and rapid stream stimulation, these paradigms may also introduce problems. Specifically, by using these paradigms, the experimental stimuli are always preceded by background stimuli. Thus, in addition to being meaningful, the experimental stimuli are also *different* from the preceding stimuli (e.g., the experimental stimuli are pronounceable, meaningful, and follow orthographic rules, whereas the background stimuli are unpronounceable, meaningless, and obey no orthographic rules). These differences between successively input stimuli are reminiscent of another ERP component, Mismatch Negativity (MMN), for which the crucial prerequisite is the physical deviance between the current event and the prevailing context. Although the modalities of stimulus presentation and the nature of the difference between successively input stimuli are different between RP and MMN, given that the deviance between experimental stimuli and background stimuli existed in all RP studies using the "preempt stimulus technique" or "rapid stream stimulation", we postulated that the difference between experimental stimuli and their preceding background stimuli may have been an important confound in previous research. For example, in studies by Martín-Loeches and his colleagues [16,18], it was shown that RP amplitude increased gradually from strings of letters, pseudowords, to words. According to the authors, this is because the RP is a gradual response to different steps of the reading process. However, because the difference between each type of experimental stimuli (strings of letters, pseudowords, to words) and their preceding background stimuli (word fragments) also changed, the increased RP amplitude might alternatively reflect the enlarged difference[1] between successively input stimuli.

This confounding factor existed in all previous RP research using the preempt stimulus technique or the rapid stream stimulation paradigm. In order to understand the key factor for eliciting RP, further study designed to separate the confounding factor—the difference between the successively input stimuli from the semantic processing of stimuli—is needed; this is the purpose of the present research.

In order to determine whether the RP could be influenced by the difference between experimental and their preceding background stimuli, the present research broke from the tradition of using meaningless word fragments as background stimuli and different kinds of images (e.g., true words, pseudowords, etc.) as experimental stimuli. Instead, we systematically altered the type of background images presented using rapid stream presentation (pseudowords and nonwords in Experiment 1 and meaningless word fragments in Experiment 2) while maintaining recognizable real words as experimental stimuli. Subjects were instructed to press a key whenever they saw a real word. We reasoned that different background stimuli would make subjects rely on different information when judging whether a stimulus was a real word, leading to different depths of processing [13]. For example, since word fragment background stimuli differed from real words at the form level, subjects could make their decisions based on lexical form without fully extracting the meaning. Conversely, for the pseudoword background condition during which background stimuli looks similar to real words, subjects would have to extract and utilize the meaning of the real words in order to make a correct response. If the RP reflects language processing and is a gradual response to the different steps of the reading process [16,17], from the word fragment, nonword, to pseudoword background conditions, RP amplitude should increase because processing level also increases. However, if RP is influenced by the detection of differences between sequentially presented stimuli, we would expect that RP amplitude should decrease from the word fragment, nonword, to pseudoword background conditions because the difference between experimental and preceding background

[1] The difference mentioned here refers to the amount of information contained in each type of stimulus. For example, compared with background stimuli, the pseudowords included more information because they were constructed following orthographic rules for Spanish. For real words, the difference between them and background stimuli was greater than that of pseudowords because they also contained meaning and sound (in addition to following orthographic rules).

stimuli is also reduced (even though the experimental stimuli, i.e., real words, are identical).

2. Experiment 1

2.1. Materials and methods

2.1.1. Participants

Sixteen undergraduate or graduate students (8 females) from Beijing Normal University participated in the experiment. They were recruited by an advertisement that offered payment for their participation. Participant age ranged from 19 to 26 years with mean age of 22.69 (SD = 2.15) years. By self-report, all were right-handed, had normal or corrected-to-normal vision, and had a negative neurological history.

2.1.2. Stimuli

There were two types of background stimuli—pseudowords (PWs) and nonwords (NWs)—and three types of experimental stimuli—real words (RWs), control stimuli 1 (CN1), and control stimuli 2 (CN2). PWs were the stimuli that followed orthographic rules for Chinese but were devoid of meaning and pronunciation. NW stimuli did not follow Chinese orthographic rules and were created by composing Chinese character components together (see Fig. 1 for examples of each type of stimulus). RW stimuli were real, one-character Chinese words. Each of these three types of stimuli differs from each other in terms of their linguistic properties (e.g., orthographic rules, pronunciation, and meanings). Specifically, the difference between NWs and RWs was larger than that between PWs and RWs. This is because the PW stimuli were constructed according to the orthographic rules for Chinese so that they looked like RWs except that they did not have meaning and pronunciation, while the NW stimuli were not only meaningless and unpronounceable but also differed from the RWs at the level of lexical form.

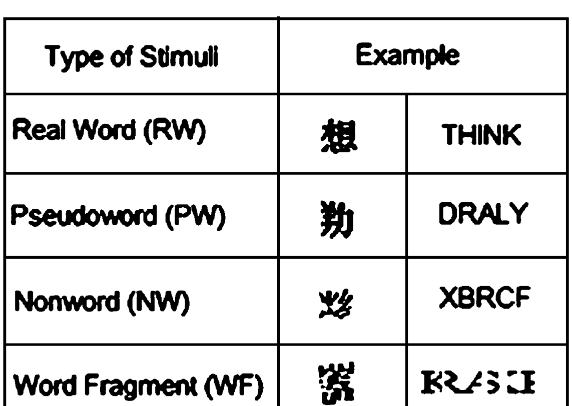

Fig. 1. Example of RW, PW, and NW stimuli used in Experiments 1 and 2. Word or letter strings in right column are the English counterpart of each type of stimuli.

Each of the two types of background stimuli had 192 samples. For RW stimuli, there were 140 samples. These 140 samples were divided equally into two groups (70 samples each). The number of strokes (a line forming part of the Chinese character, for example, the character 二, which means 'two', has two strokes) and word frequency (based on Xiandai Hanyu Pinlu Cidian [Modern Chinese Frequency Dictionary], [31]) were matched between these two groups. The type 1 and type 2 control stimuli were randomly selected from the two background stimuli pools, respectively, each containing 70 samples. Under each of the two background conditions, only one type of control stimulus was used and these stimuli were selected from the same sample pool as the background stimuli.

All stimuli (background stimuli, control stimuli, and real words) were presented 2 cm high by 2 cm wide. At the 80-cm viewing distance, stimuli were 1.43° high by 1.43° wide. During the experiments, all stimuli were presented white-on-black on a computer monitor, controlled by the Gentask module of the STIM package (NeuroScan Inc.).

2.1.3. Procedure

Rapid steam stimulation, the main procedure for obtaining the RP [23], was applied. All the stimuli (background stimuli, control stimuli, and real words) were displayed with a stimulus onset asynchrony (SOA) of 200 ms and an interstimulus interval (ISI) of 0 ms. The computer displayed background stimuli most of the time, with experimental stimuli (real word or control) interspersed periodically. Stimuli were separated into trials. An example of such a trial is shown in Fig. 2. Each trial contained one experimental stimulus (either a real word or a control stimulus) and 4 to 10 (the specific number was determined randomly) preceding background stimuli.

There were 280 total trials, which were equally divided into two blocks. In one block, both the background stimuli and control stimuli were PWs. In the other block, both background and control stimuli were NWs. Both groups of RWs were used in these two blocks, respectively, and the arrangement was counterbalanced between subjects. The sequence of these two blocks was also counterbalanced between subjects.

Participants were instructed to press a button every time they detected an RW. Before the experiment, they were allowed to practice until they felt comfortable with the speed of stimulus presentation as well as the task. Before each trial, participants were allowed to take a rest and press the start button to begin the next trial. After the first block, they were allowed to rest for 10 min.

2.1.4. Electrophysiological recording

Electroencephalographic (EEG) data were recorded using the Scan4.2 package (NeuroScan, Inc.). A Quick-cap with 30 tin scalp electrodes (FP1, FP2, F7, F3, FZ, F4, F8, FT7, FC3, FCZ, FC4, FT8, T7, C3, CZ, C4, T8, TP7, CP3, CPZ, CP4, TP8, P7, P3, PZ, P4, P8, O1, OZ, O2), VEOG, and

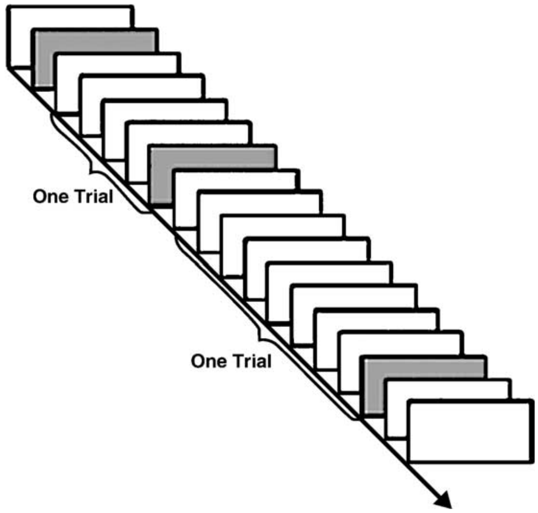

Fig. 2. An example of trials in the rapid stream stimulation. Each trial contained one experimental stimulus (either RW or CN) and 4 to 10 (the specific number was determined randomly) preceding background stimuli (BK). The white boxes indicate background stimuli and the gray boxes indicate experimental stimuli (RW or CN). All the stimuli (BK, CN, and RW) were presented for 200 ms and there was no interval between stimuli.

HEOG were used. All scalp electrodes were referenced to the link of the left and right mastoids.

Electrode impedances were always kept below 5 kΩ. The EEG and EOG were amplified with gains of 100,000 and 1000, respectively, with band pass of 0.05–100 Hz. Data were continuously digitized at a rate of 500 Hz.

2.1.5. Data analysis

For the behavioral data, trials with response omission, premature response (reaction time shorter than 300 ms), and late response (reaction time longer than 1000 ms) were counted as error responses. Mean reaction time was calculated after excluding those trials.

The EEG data were divided into 1000-ms epochs, including 100 ms baseline before the onset of the stimulus. The blink was corrected by using the eye movement reduction algorithm provided by the Scan4.2 package (NeuroScan, Inc.). Other artifacts exceeding 65 μV were rejected off-line. Different averages were calculated separately for each background condition, as well as for each type of experimental stimuli (RWs and CN under the NW background condition; RWs and CN under the PW background condition). As with the behavioral data, error trials were excluded from the analysis of electrophysiological data. Peak latency and RP amplitude were quantified. Peak amplitude was determined by a computer algorithm that found the most negative value in the time window of 200–380 ms after experimental stimulus onset. Because the peak latency of the RP varied under different experimental conditions, there was some adjustment of the time window starting point under some experimental conditions. That is, we did not always start 200 ms after stimulus onset,[2] but the length of each epoch was always 180 ms. Latency was measured using an algorithm that determined the times before and after the peak when the amplitude was 40% of the peak amplitude. The time value that equally divided the area under the peak within these limits defined RP latency [27].

2.2. Results

2.2.1. Performance

For the NW background condition, the error rate was 14.32% (SD = 0.13) and the mean reaction time was 529.46 ms (SD = 59.66). For the PW background condition, the error rate was 44.48% (SD = 0.13) and the mean reaction time was 632.01 ms (SD = 0.13). The difference between these two background conditions was significant for both error rate (t_{15} = 7.96, P < 0.001) and reaction time (t_{15} = 10.12, P < 0.001).

2.2.2. Electrophysiology

The time windows used when measuring RP amplitude and peak latency elicited by RW, using NW and PW backgrounds, were 250 to 430 ms and 300 to 480 ms, respectively. During these time windows, an RP-like negative wave was found at electrodes within the bilateral inferior parieto-occipital area. The maximum amplitude for the left and right hemispheres was found at P7 and P8, respectively. At electrode P7, the RP amplitude and peak latency values under the NW and PW background conditions were, respectively: −4.77 μV and 334.63 ms, −2.54 μV and 396.00 ms. At electrode P8, the RP amplitude and peak latency values under the above two conditions were, respectively: −3.99 μV and 338.38 ms, −2.74 μV and 413.25 ms.

The two types of control stimuli (CN1 and CN2), which were selected from the same sample pool as the background stimuli, produced only a driving rhythm at about 5 Hz (Fig. 3), timing locked to the transition from one stimulus to another.

A 2 (Electrode Site) × 2 (Background Stimulus Type) repeated-measures ANOVA using RP amplitude and peak latency elicited by RWs as dependent measures were performed. For RP amplitude, both the main effects of background stimulus type and the electrode site × background stimulus type interaction were significant ($F_{1,15}$ =

[2] The reason that we did not always start 200 ms after stimulus onset was that the peak RP latency varied under different background conditions. Previous research using meaningless WFs as background stimuli elicits an RP peak latency of less than 300 ms [24]. However, in the present research, the peak RP latency elicited by RWs generally exceeded 300 ms when presented under NW or PW background conditions. To measure peak latency and amplitude precisely, we chose to adjust the time window depending on the experimental condition under which the RP was produced. Our time window was 180 ms in duration, starting at the earliest time point from which all peak latencies could be included in the time window.

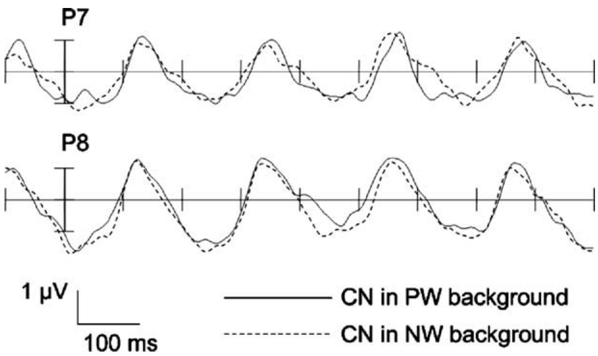

Fig. 3. Experiment 1. Grand-average waveforms for each type of control stimuli (NWs or PWs). The two types of control stimuli did not elicit an RP when they were preceded by identical background stimuli. Rather, they elicited a driving rhythm at about 5 Hz.

15.88, $P = 0.001$; $F_{1,15} = 5.14$, $P = 0.039$, respectively). The main effect of electrode site was not significant ($F_{1,15}$ = 1.33, P = 0.267). Tests of simple effects revealed that the impact of background stimulus type was significant at both P7 and P8. Specifically, the RP amplitude was larger under the NW background condition than under the PW background condition (Fig. 4) at both electrode P7 ($F_{1,15} = 18.22$, P = 0.001) and electrode P8 ($F_{1,15}$ = 7.71, P = 0.014). However, the effect of electrode site was not significant under either of the two background conditions. Under both NW and PW background conditions, RP amplitude was comparable at P7 than at P8 electrodes (NW: $F_{1,5} = 3.81$, P = 0.070; PW: $F_{1,15}$ = 0.68, P = 0.423). For RP peak latency, only the main effect of background stimulus type was significant, in which the peak latency during the NW background condition was shorter than during the PW background, ($F_{1,15}$ = 43.20, P < 0.001). Both the main effects of electrode site and the electrode site × background stimulus type interaction were not significant ($F_{1,15}$ = 1.17, P = 0.297; $F_{1,15}$ = 0.48, P = 0.501, respectively).

As the above analyses were based on the difference wave as opposed to the original wave,[3] whether the results reflected a difference in the original wave or the difference between the ERP elicited by the CN stimuli needed further clarification. A 2 (Electrode Site) × 2 (Background Stimulus Type) repeated-measures ANOVA on ERP amplitude and peak latency elicited by the two types of CN stimuli during the time window of 200–380 ms was performed. For amplitude and peak latency, the main effects of background stimulus type (for amplitude, $F_{1,15}$ = 0.45, P = 0.514; for peak latency, $F_{1,15}$ = 0.002, P = 0.963) and electrode site (for amplitude, $F_{1,15}$ = 3.36, P = 0.087; for peak latency, $F_{1,15}$ = 0.48, P = 0.498) were nonsignificant, as was their interaction effect (for amplitude, $F_{1,15}$ = 0.004, P = 0.952; for peak latency, $F_{1,15}$ = 0.15, P = 0.702).

2.3. Discussion

Reaction time and error rate were greater during the PW compared to the NW background condition. This indicates that people needed more time to make their decision under the PW background condition, purportedly because they also had to process semantic information instead of making a judgment based on form alone. That is, the depth of processing was relatively deeper under the PW background condition.

If the RP is a gradual response to the different steps in the reading process [16,18], this deeper processing under the PW background condition should have led to higher RP amplitude. However, the result was in the opposite direction: RP amplitude was significantly larger under the NW background condition than in the PW background condition.

In contrast, the present data fit our interpretation very well. Specifically, although the RWs used in the two background conditions were identical, the differences between these RW stimuli and their background stimuli were not equal: The difference between the RWs and the NWs was larger than that between the RWs and PWs. Consequently, the RP elicited by these RWs using the NW background had higher amplitude and shorter peak latency compared to the RP elicited by the same RWs under the PW background. This strongly supports our hypothesis that

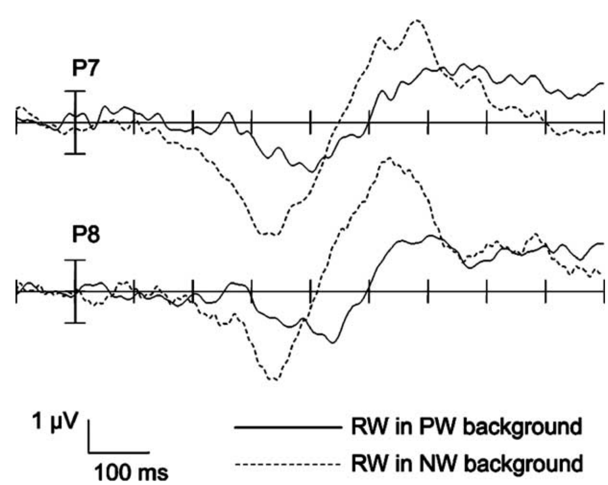

Fig. 4. Experiment 1. Grand-average difference waveforms after subtracting the control trials (NWs or PWs) from each of the RW waveforms. RWs under the NW background condition elicited an RP with higher amplitude and shorter peak latency than the RP elicited by the same group of RWs under the PW background condition.

[3] We did not report data measured from the original wave. Instead, we used the difference wave obtained by subtracting the ERP elicited by the control stimuli from the ERP elicited by RWs. We chose to use the difference wave because, in the present experiment, it is very difficult to detect the RP peak from the original wave under the two background conditions (and especially the PW background condition). Consequently, the corresponding RP amplitude and peak latency were also very difficult to determine. As Rudell [22] noted, the difference wave is the best way to present the RP and the difference wave is similar to that from the original wave (Personal communication with Rudell, 1/10/2002). Thus, we used data from the difference wave.

differences between sequentially input stimuli in the rapid stream stimulation paradigm may influence RP.

There was one additional issue that still required attention. Because the data used in the analyses were measured from the difference wave obtained by subtracting the ERP elicited by the CN stimuli from the ERP elicited by RWs, the difference in ERP elicited by the CN stimuli may have contributed to the RP differences mentioned above. However, statistical analyses did not show any significant difference in either amplitude or peak latency between the ERP elicited by the NW control stimuli and the PW control stimuli. This further suggests that RP can be modulated by the difference among subsequently input stimuli.

If the above conclusion is correct, one would expect that RP amplitude and peak latency would get higher and shorter when the difference between background and experimental stimuli is increased. In the following experiment, we used word fragments (WFs) as the background stimuli. WF stimuli were constructed by first cutting Chinese characters into pieces and then reorganizing them randomly so that participants could not recognize any meanings. Compared to the difference between NWs and RWs, the difference between WFs and RWs was greater because NWs included complete components of a Chinese character (despite not following orthographic rules for Chinese). WFs, conversely, were composed of unrecognizable word pieces. Our hypothesis would be further supported if RP amplitude and peak latency are higher/shorter when using background stimuli which were more drastically different relative to the experimental stimuli.

3. Experiment 2

3.1. Materials and methods

3.1.1. Participants

Twenty undergraduate or graduate students (10 female) from Beijing Normal University participated in the experiment. None of them had participated in Experiment 1. They were recruited by an advertisement that offered payment for their participation. Their ages ranged from 18 to 24 years with a mean age of 21.2 (SD = 1.76) years. An ANOVA (four levels: females in Experiment 1, males in Experiment 1, females in Experiment 2, and males in Experiment 2) was carried out to examine whether their ages matched those of participants in Experiment 1. Results revealed no significant differences ($F_{3,32}$ = 1.76, P = 0.174). By self-report, all subjects were right-handed, had normal or corrected-to-normal vision, and had negative neurological histories.

3.1.2. Stimuli

There were two types of experimental stimuli, real words (RWs) and word fragments (WFs). Each of them had one hundred samples. The RWs were selected from the same sample pool used in Experiment 1 and were matched on word frequency and number of strokes with the two groups of RWs used in Experiment 1. The WFs, which acted as control stimuli, were constructed by cutting Chinese characters into pieces and then reorganizing them randomly so that participants could not recognize any meanings (see Fig. 1 for an example and its counterpart in English). The background stimuli were randomly selected from the same WF sample pool. The presentation of stimuli was identical to that of Experiment 1: All stimuli were 2 cm high by 2 cm wide such that, at the 80-cm viewing distance, all stimuli were 1.43° high by 1.43° wide.

3.1.3. Procedure

The details were the same as described in Experiment 1. Rapid stream stimulation was applied. Participants were instructed to press a button every time they detected an RW stimulus.

3.1.4. Electrophysiological recording and data analysis

Both behavioral and continuous EEG data were recorded and analyzed following the procedures outlined in Experiment 1, except that we used a Quick-cap with 62 tin scalp electrodes (FP1, FPZ, FP2, AF7, AF3, AF4, AF8, F7, F5, F3, F1, FZ, F2, F4, F6, F8, FT7, FC5, FC3, FC1, FCZ, FC2, FC4, FC6, FT8, T7, C5, C3, C1, CZ, C2, C4, C6, T8, TP7, CP5, CP3, CP1, CPZ, CP2, CP4, CP6, TP7, P7, P5, P3, P1, PZ, P2, P4, P6, P8, PO7, PO5, PO3, POZ, PO4, PO6, PO8, O1, OZ, O2). Different averages were calculated separately for each type of experimental stimulus (RW and CN).

3.2. Results

3.2.1. Performance

The error rate was 14.60% (SD = 0.18) and the mean reaction time was 557.71 ms (SD = 76.79). Neither the error rate (t_{34} = 0.05, P = 0.958) nor the reaction time (t_{34} = 1.21, P = 0.236) deviated significantly from those under the NW background condition in Experiment 1. However, both the error rate ($t_{1,34}$ = 5.56, P < 0.001) and the reaction time ($t_{1,34}$ = 3.05, P = 0.004) were significantly less relative to those under the PW background condition in Experiment 1.

3.2.2. Electrophysiology

The time window to measure RP amplitude and peak latency elicited by RWs was 200 to 380 ms. During this time window, an RP-like negative wave was found at electrodes within the bilateral inferior parieto-occipital area. The maximum amplitude for the left and right hemispheres was found at P7 and P8, respectively. RP amplitude and peak latency values elicited by the RWs were −6.37 μV and 318.20 ms for electrode P7 and −6.00 μV and 305.90 ms for electrode P8. The CN stimuli produced only a driving rhythm at about 5 Hz (Fig. 5), timing locked to the transition from one stimulus to another.

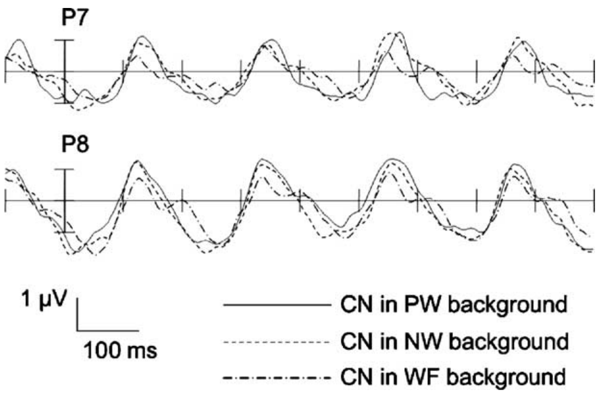

Fig. 5. Experiments 1 and 2. Grand-average waveforms for each type of control stimuli (WFs, NWs, or PWs). The three types of control stimuli did not elicit an RP when they were preceded by identical background stimuli. Rather, they elicited a driving rhythm at about 5 Hz.

To determine whether the enlarged difference between the experimental stimuli and background stimuli produced changes in the RP, the RPs elicited in our present experimental condition (where meaningless WFs were used as background stimuli) were compared with those recorded under NW and PW background conditions (in Experiment 1), respectively. A 2 (Electrode Site) × 2 (Background Stimulus Type) mixed-design ANOVA with electrode site as the within-subjects variable was performed with RP amplitude and peak latency acting as dependent measures for each of the two comparisons.

When comparing RP amplitude elicited using the WF background versus the NW background, only the main effect of background stimulus type was significant. Specifically, RP amplitude was higher in the WF background condition than in the NW background condition (Fig. 6; $F_{1,34} = 4.35$, $P = 0.045$). Both the main effects of electrode site ($F_{1,34} = 2.46$, $P = 0.126$) and the electrode site × background stimulus type interaction ($F_{1,34} = 0.31$, $P = 0.584$) were not significant. For RP peak latency, only the main effect of background stimulus type ($F_{1,34} = 4.79$, $P = 0.036$) was significant. Neither the main effect of electrode site ($F_{1,34} = 0.55$, $P = 0.465$) nor the electrode site × background stimulus type interaction ($F_{1,34} = 1.92$, $P = 0.175$) was significant.

When comparing the RP elicited using the WF background versus the PW background, only the main effect of background stimulus type was significant for RP amplitude. Specifically, the RP amplitude when using the WF background was higher than when using the PW background (Fig. 6; $F_{1,34} = 16.95$, $P < 0.001$). Both the main effects of electrode site and the electrode site × background stimulus type interaction were not significant ($F_{1,34} = 0.06$, $P = 0.802$; $F_{1,34} = 0.72$, $P = 0.403$, respectively). For RP peak latency, only the main effect of background stimulus type ($F_{1,34} = 62.42$, $P < 0.001$) was significant. Neither the main effect of electrode site ($F_{1,34} = 0.08$, $P = 0.783$) nor the electrode site × background stimuli type interaction ($F_{1,34} = 2.74$, $P = 0.107$) was significant.

As in Experiment 1, the above analyses used data measured from the difference wave. In order to exclude the possibility that the ERP elicited by the control stimuli caused the above differences, a 2 (Electrode Site) × 2 (Background Stimulus Type) mixed-design ANOVA using electrode site as the within-subjects variable was performed on ERP amplitude and peak latency when using the three types of control stimuli (WFs, NWs and PWs). Comparing ERPs elicited by the WF control stimuli and NW control stimuli, only the main effect of electrode site was significant for amplitude. Specifically, the amplitude at electrode P8 was higher than that at electrode P7 ($F_{1,34} = 5.50$, $P = 0.025$). Neither the main effect of background stimulus type ($F_{1,34} = 1.67$, $P = 0.204$) nor the interaction effect ($F_{1,34} = 0.09$, $P = 0.762$) was significant. For peak latency, the main effects of background stimulus type and electrode site were nonsignificant, as was their interaction ($F_{1,34} = 0.96$, $P = 0.334$; $F_{1,34} = 1.14$, $P = 0.293$; $F_{1,34} = 0.11$, $P = 0.740$, respectively).

When comparing the driving rhythms elicited by the WF control stimuli and the PW control stimuli, only the main effect of electrode site was significant for amplitude. The RP amplitude at P8 was higher than that at P7 ($F_{1,34} = 7.38$, $P = 0.010$). Both the main effects of background type and the background type × electrode site interaction were not significant ($F_{1,34} = 0.93$, $P = 0.341$; $F_{1,34} = 0.10$, $P = 0.756$, respectively). For peak latency, the main effect of background stimulus type and electrode site, as well as their interaction, was not significant ($F_{1,34} = 0.86$, $P = 0.360$; $F_{1,34} = 0.42$, $P = 0.523$; $F_{1,34} = 0.006$, $P = 0.939$, respectively).

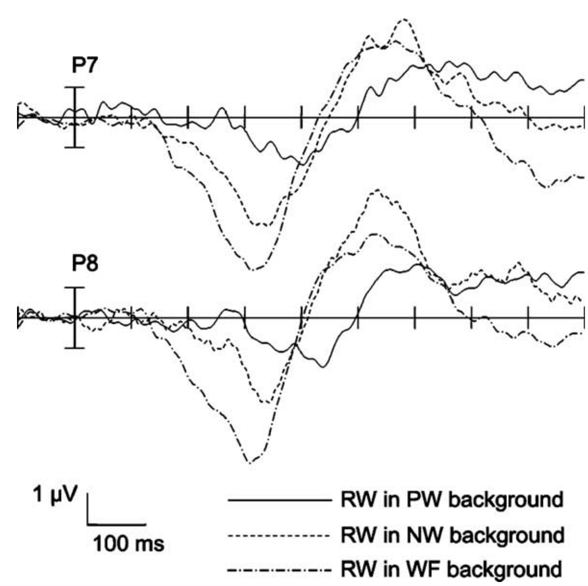

Fig. 6. Experiments 1 and 2. Grand-average difference waveforms after subtracting control trials (WF, NW, or PW) from each of the RW waveforms. The same RWs under different background conditions elicited RPs with different amplitudes and peak latencies. Specifically, from PW, NW, to WF background conditions, the amplitude of RP became larger and the peak latency of RP became shorter.

3.3. Discussion

As expected, RP amplitude and peak latency became higher/shorter after the difference between RW and background stimuli was enlarged (Fig. 6).

Though analyses revealed that ERP amplitude elicited by the three kinds of control stimuli were affected by electrode site, ERP amplitude was the same across all three background conditions at each electrode site. Thus, similar to Experiment 1, the discrepancy between these difference waves appears to be due to the difference between the original waves elicited by the RWs under the three background conditions. Changes in RP amplitude and peak latency can only be explained by the increased difference between the RWs and their preceding background stimuli. This further supports the notion that the difference between successively input stimuli may influence RP—the larger the difference, the higher the amplitude of RP.

At both electrodes P7 and P8, the peak RP latency elicited by RWs got gradually shorter from the PW, NW, to WF condition and all of the differences were significant. Why did peak RP latency change gradually across the three background conditions? One plausible reason is that these three kinds of background stimuli started to deviate from the RWs at different stages of written language processing. For example, the WFs were different from the RWs at the lexical form level, which was at the first stage of written language processing. For the PW background stimuli, because they were constructed according to the Chinese orthographic rules and looked similar to RWs, the difference between RWs and PWs could only be detected after extracting the meaning and/or the pronunciation of the RWs. This delayed detection (compared with the WF and NW background conditions) may have resulted in the longest peak RP latency in the PW background condition, potentially explaining its longest reaction time.

4. General discussion

In the present research, we systematically changed the difference between experimental stimuli and their preceding background stimuli by using the same RWs under different background conditions. Despite using the same RWs across conditions, RP amplitude became higher and the peak latency became shorter as the difference between RWs and background stimuli increased.

Although previous RP research has supported the notion that RP is related to semantic processing [7–9,16–18], this theory does not adequately explain our data. In the present research, the subjects' task was to respond whenever they detected an RW under WF, NW, or PW background conditions. According to Joordens and Becker [13], different background stimuli may induce subjects to rely on different information when making judgments about whether a stimulus is an RW, thereby leading to different processing depths. If the RP is a gradual response to all steps in the reading process, and its amplitude is proportional to the level of information available in the stimulus (for example, for PWs, the highest level of information is orthography while RWs contain both orthographic and semantic information), then the RP amplitude should increase from the WF background condition to the PW background condition. However, the data collected in the present studies fail to support this line of reasoning. Relatedly, recent research by Hinojosa et al. [11] found that depth of processing (lower–upper case discrimination judgment vs. the detection of animal names) does not affect RP (latency, amplitude, and topographic distribution). According to the authors, their data suggest that RP may reflect early semantic processing that is independent of processing depth. Based on this notion, we would have expected that the RP elicited by the same RWs under the three background conditions would be the same. This also was not the case, further leading to question whether the RP data collected when using the rapid stream stimulation paradigm is related to semantic processing.

Previous research has also shown that RP peak latency may be affected by factors such as word image degradation [25], word frequency [24], word difficulty [27], individual reading ability [26,27], and priming [26]. The priming paradigm was not used in the present research and the RWs used in both experiments were presented without degradation. Though word difficulty was not specifically controlled, RWs used in the present research were selected from the same pool. Moreover, both word frequency and number of strokes were matched between experimental conditions, making it unlikely that there was a significant difference in word difficulty among the three background conditions. This is especially true because word frequency is closely related to word difficulty [27]. We also did not control for subject reading level. However, because all subjects in these two experiments were undergraduate or graduate students of Beijing Normal University, it can be cautiously inferred that they had a generally high-level ability to read with comprehension and it is relatively unlikely that there was a significant difference between the two groups.

The (1) failure of our data to support prior RP theory and (2) the confounding factor introduced by the rapid stream stimulation paradigm lead to the conclusion that, RP is influenced by the detection of differences between sequentially input stimuli when using the preempt stimulus technique or the rapid stream stimulation paradigm. The larger the difference between stimuli, the higher the RP amplitude and the shorter the RP peak latency. Our RP hypothesis is consistent with prior research. As previously mentioned, factors such as word degradation, word difficulty, word frequency, as well as individual reading ability, etc., result in RP changes. While each of these factors may affect language processing, these data do not contradict our tenet that RP is influenced by the detection of differences between successively input stimuli. Because the detection of differences relies on information provided by other information processing systems, any factor that could influence those related systems would eventually affect detection and, hence, the RP. For example, it is generally believed that the higher the word frequency, the faster it can be processed (e.g., the 'word frequency effect' [1,21,28,30]). Thus, compared to low-frequency words, processing high-frequency words and detecting the difference between such words and their preceding background should be faster. Consequently, as found in Rudell's study [24], it would be expected that high-frequency words would elicit an RP with shorter peak latency as compared to low-frequency words.

Moreover, our new hypothesis may provide a better explanation of previously collected RP data. For example, in one study by Hinojosa and colleagues [7], Chinese characters (which were meaningless to subjects) elicited an RP, though its amplitude was smaller relative to that of Spanish words and pictures (which were comprehensible to subjects). Hinojosa et al. [7] attributed this to "the top–down attentional processes, as these stimuli might resemble to some extent the attended (conceptual containing) stimuli". They also suggested that "the organized structure of Chinese characters as compared with the random structure of the control stimuli and, therefore, their higher resemblance to conceptual stimuli, would be the cue that might initiate the processes involved in RP generation". Considering the large difference between the lexical forms of these two languages, we respectfully offer a different interpretation of their data. Specifically, all of their experimental stimuli—Spanish words, pictures, and Chinese characters—were preceded by background stimuli containing randomly chosen parts of Spanish words and pictures. Thus, all experimental stimuli differed from background stimuli. If the RP is also influenced by the detection of differences between sequentially input stimuli, the notion that they all elicited an RP is not particularly surprising. Moreover, because the Chinese characters were meaningless to subjects, the difference between them and their preceding background stimuli was merely at the form level. As for the Spanish words and pictures, there was a greater difference between these stimuli and the background stimuli because both were meaningful to subjects. Consequently, the RP amplitude elicited by the Chinese characters would be expected to be attenuated compared to the other two types of stimuli.

Two additional issues require attention. One is that our new RP hypothesis is enlightened by the generally accepted explanation of MMN, although there are many differences between these two ERP components. MMN is well defined in the auditory modality (e.g., [20]). Although some recent data provide convincing evidence for the existence of an MMN homologue in the visual modality (e.g., [2,5,20]), there are still distinctions between RP and visual MMN. For visual MMN, researchers have focused on stimulus differences with regard to physical attributes, such as motion direction [15,19], form [3,4,29], orientation [2], spatial frequency [6,14], and color [5]. As for the RP, the present research indicates that it might reflect differences at higher cognitive level (e.g., deciphering orthographic rules, meaning, and familiarity). The fact that the observed RP latency was longer than that of the visual MMN is likely due to the higher cognitive processing in the RP task.

The second issue is that, although our research indicated that the RP can be influenced by the detection of differences among successively input stimuli, it is unclear whether a difference is necessary to generate an RP. In Experiment 1, NWs and PWs did not elicit an RP when they were preceded by the same background stimuli. However, these types of stimuli did elicit an RP when they were different from background stimuli (as shown in the studies by Martín-Loeches and colleagues [16,18]). Thus, it appears that the difference between sequentially input information is necessary for RP generation: If this difference disappears, then the RP would not be elicited. However, both Rudell's early RP research (e.g., [22]) and a recent study by Iglesias and colleagues [12] reported that RP could be elicited by RWs regardless of whether or not they were preceded by meaningless background stimuli. Moreover, RP amplitude appears to be enhanced when RWs are preceded by different background stimuli [12,22]. Based on the results of their research [12], Iglesias and colleagues concluded that the key factor for eliciting an RP is semantic processing of the stimuli. As for the enhancement of the RP amplitude, they argued that it was due to the background stimuli being inserted between two experimental stimuli, which could eliminate the overlapping ERP fluctuations caused by the RWs. However, to the authors of present research, the enhanced RP amplitude may result from the detection of differences between RWs and their preceding background stimuli. There are two important reasons why we stand by this theory. First, our hypothesis explains the present data whereas the notion that RP reflects semantic processing fails to do so. Second, although Iglesias and colleagues [12] did not explicitly mention this, their Fig. 2 suggests that meaningless background stimuli could also elicit an RP-like component when preceded by real words, supporting our hypothesis that the detection of differences between sequentially presented stimuli may also influence RP.

5. Conclusions

Based on the results of the present research, we conclude that the detection of differences between sequentially input stimuli can influence RP. We cannot reject the notion that RP generation is caused by recognition of stimuli, however, because other research [12,22] has found that the RP may be elicited even when there are no such differences. Taken together, we conclude that both the recognition of the experimental stimuli and the detection of the differences between successively input stimuli could elicit the posterior negativity at around 200 to 400 ms post-stimulus onset. It is necessary to clarify whether RP changes are caused by the processing of stimuli, or by the detection of difference between successively input stimuli before any conclusion can be made. For example, the gradually increased RP amplitude found in Martín-Loeches and colleagues' research [16,18] might not necessarily indicate that RP is a gradual response to different steps of the reading process. Rather, it may be caused by the increased difference between the background stimuli (word fragments) and different types of experimental stimuli (random letter strings, pseudowords, and real words). Systematically designed studies are needed to further investigate the relationship between the RP, semantic processing, and the detection of differences between stimuli.

Acknowledgments

This study was funded by the grant, National PANDENG project of China (95-special-09). The authors thank Alan P. Rudell for his helpful discussions and Wei Meng and Huachun Chen for their assistance on data analysis.

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