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Electrophysiological Correlates of Successful Visual Mental Imagery

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Abstract The spatiotemporal analysis of brain activation during the execution of visual mental imagery tasks was performed in 14 normal young adult subjects using ERPs. Results showed that Successful mental imagery elicited a more positive ERP deflection (P600-1000) than Unsuccessful mental imagery between 600–1000 ms, which was possibly related to forming visual mental imagery on the basis of initial stimuli classification and identification. Then, a greater slow positivity (P1000-1500) in Successful mental imagery as compared to unsuccessful mental imagery might be associated with detected over the frontal scalp regions between 1000-1500 ms, which might be involved in maintaining mental imagery and making decisions in working memory.

Keywords Chinese oracle bone script, Visual mental imagery, Event-Related potentials (ERPs)

1. Introduction

The visual mental imagery refers to the representation in an individual's mind of the physical world outside of that individual, which was associated with visual perception (Ganis et al., 2004). With the development of brain imaging techniques (e.g., fMRI, PET), we could record the brain activity associated with visual mental imagery and visual perception precisely. Functional magnetic resonance imaging (fMRI) is a noninvasive functional neuroimaging procedure using MRI technology that measures brain activity by detecting associated changes in blood flow, while Positron emission tomography (PET) is a nuclear medicine, functional imaging technique that produces a three-dimensional image of functional processes in the body. Many previous studies using fMRI or PET have provided some neural evidence of visual mental imagery and visual perception (Roland and Friberg, 1985; Goldenberg *et al.*, 1989; Kosslyn *et al.*, 1997, 2001, 2006; Brockmole *et al.*, 2002; Kosslyn and Thompson, 2003; Denis et al., 2012). Kosslyn et al., (2001) have pointed that visual mental imagery and visual perception might share numerous common neural representations. In addition, some brain damage studies also reported similar deficits in imagery and perception. (Bisiach & Luzzatti, 1978; Shuttleworth Jr *et al.*, 1982)

On the other hand, some researchers suggest that there were dissociable mechanisms underlying mental imagery and visual perception, including studies with healthy participants (Knauff and colleagues, 2000; Roland and Gulyas, 1994), studies with lesion brain (Basso *et al.*, 1980; Behrmann *et al.*, 1992) and studies with blind subjects (Bertolo et al., 2005). For example, Ganis et al., (2004) found that visual mental imagery and visual perception might use the same neural machinery, and that the overlap brain regions between these two processes were in frontal and parietal regions instead of temporal and occipital regions. These results may indicate that visual mental imagery could dissociate in the sensory process and integrated in the cognitive control process. In addition, in Moro et al.'s study (Moro *et al.*, 2008), one patient showed pure visual mental imagery deficits in the absence of imagery deficits in other sensory domains, while the other patient showed both visual and tactile imagery deficits. Their analysis of the lesions showed a massive involvement of the left temporal lobe in both patients and a bilateral parietal lesion in one patient, and their results indicated that visual imagery deficits could occur independently from deficits of visual perception and the left temporal lobe played an important role in visual mental imagery (Moro *et al.*, 2008). Therefore, the neural correlates of visual mental imagery seem to partly different from that of visual perception. These findings indicate that mental imagery might share common brain areas with other major cognitive functions, such as memory, and movement, depending on the nature of the imagery task (Gyselinck and Pazzaglia, 2012; Kunzendorf, 2013).

Besides many previous studies using PET or fMRI to provide new insights into the cortical anatomy of mental imagery function, other previous studies used event-related

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potentials (ERPs) to investigate the neural time course of visual perception and visual mental imagery. The ERP and fMRI were the most popular neuroscience technology using in the psychology. The ERP was characterized by high time resolution, while the fMRI was characterized by high spatial resolution. However, the ERP results were also mixed. For example, Farah et al. (1988) found a "content-specific" effect of mental imagery during a visual letters task. Qiu et al. (2007) also compared spatiotemporal cortical activation patterns during the visual perception and visual mental imagery processing. There results showed that visual mental imagery elicited a more negative ERP deflection (N240) than visual perception between 150–250 ms, which might be related to forming visual mental imagery early. Then, a greater negativity (N520) in visual mental imagery as compared to visual perception was detected over the right frontocentral scalp regions. In addition, Ganis and Schendan (2008) find that visual mental imagery and perception yielded opposite adaptation effects on early brain potentials. Wu et al. (2012) suggested that the effect of visual imagery on visual identification is content-specific and that imagery-perception interaction might depend on the task.

Most of these studies used pictures as experimental materials, which let participants have different visual perception during visual mental imagery task. In the present study, we focused on the neural time course of the successful mental imagery that compared with the unsuccessful mental imagery. We want to explore the temporal course of brain processes underlying successful visual mental imagery. Therefore, in order to control the physical characteristics, we developed a task that uses Chinese oracle bone scripts (the predecessor and prototype of Chinese Characters) as materials. Oracle bone script is one of the oldest known forms of Chinese written language. The script was carved on tortoise shells and ox scapulas (shoulder blade) bones, which are presumed their origins as pictographs and signs. That is to say, they represent true writing in that they are an orthographic representation of language (as opposed to a picture). It is even possible for an untrained reader of modern Chinese to recognize many of the ancient characters because they are true and visual pictures (see our examples in Stimuli Appendix).

Thus, the purpose of the present study was to explore spatiotemporal cortical activation patterns in the processing of successful visual mental imagery of Chinese oracle bone script by using high-density (64 channels) ERP recording. First, we intended to determine the ERP components (early ERP components, e.g., N1, P2, N2, and late ERP components: P3, slow negative or positive components) that would be involved in the different stages of processing of visual mental imagery and whether there were any differences between successful and unsuccessful mental imagery conditions. We assumed that the neural mechanism for the processing of successful mental imagery and unsuccessful mental imagery might be different due to top-down control influences. This premise is based on previous fMRI studies (Moro *et al.*, 2008; Mechelli *et al.*, 2004; Bartolomeo, 2008) that illustrate the top-down influences from superior parietal areas appear to contribute to the generation of mental images, regardless of their content and duration. In the present study, the top-down control process could appear in the successful mental imagery as compared to unsuccessful mental imagery. The methods of ERP recordings and voltage maps can provide critical temporal information for analyzing the functional neuroanatomy of cognitive processes of successful mental imagery. The anatomic specificity data of fMRI mapping obtained from previous studies and the time resolution of ERP recordings enable the characterization of the functional roles of specific brain areas in the processes of successful mental imagery. Accordingly, we hypothesized that successful mental imagery could elicit two positive ERP components than unsuccessful mental imagery in the late time windows. One ERP component might be associated with forming mental imagery; the other might be related to maintaining mental imagery.

2. Material and Methods

2.1. Subjects

Fourteen healthy undergraduate students (7 men, 7 women) from Southwest University (Chongqing) in China (average age 20.9, range 18–23), whose mother tongue was Chinese, participated in the study. All subjects gave written informed consent, were right-handed, had no history of current or past neurological or psychiatric illness, and had normal or corrected-to-normal vision. In addition, all subjects were paid 20 Yuan at the end of the experiment. In addition, our experiment was reviewed and approved by the IRB of Southwest China University.

2.2. Stimuli and Procedure

The stimuli comprised 150 Chinese characters [familiar concrete noun and verb: e.g., 马 (horse)] and 150 corresponding Chinese oracle bone scripts [e.g.,  (horse)] (More samples in the Stimuli Appendix). The size of Chinese character was Song Ti No.22 which is about 1.5× 2.0 cm, and the size of Chinese oracle bone script was 1.5 × 2.0 cm [1.4° (horizontal) × 1.9° (vertical)].

The order of experimental procedure was illustrated in Figure 1. First, the fixation point appeared for 300 ms at the center of the screen. Then, a Chinese character appeared for 600 ms as cue word. When the Chinese character disappeared, the corresponding Chinese oracle bone script was presented for 2500 ms after a 200–400 ms interval randomly. Subjects were required to make a judgment whether the Chinese oracle bone script (pictograph) was visual and lively representation to the real object or behavior that they were instructed to imagine. Finally, when a signal of "*" appeared in the center of screen, they were required to press "1" key if they think that the Chinese oracle bone script was visual and lively (Successful mental imagery) and to

press "2" key if not (Unsuccessful mental imagery).

Table 1. Summary of results for the ANOVAS in each time window

	judgement type		electrode site		task type ×electrode	
Time (ms)	*F*	*P*	*F*	*P*	*F*	*P*
650-1000	13.717	0.002	20.764	0.000	4.665	0.002
1000-1500	7.733	0.014	14.665	0.000	3.032	0.012
1500-2000	1.829	0.196	12.093	0.000	2.239	0.041
2000-2500	1.948	0.183	8.033	0.000	1.938	0.086

The total experiment was divided into a practice phase and a test phase. To familiarize the subjects with the procedure of this task and pressing of the response buttons, a practice phase was designed during which subjects had to finish 10 trials. The formal test stage was composed of 4 blocks and each block had 35 trials. The stimuli appeared at random. Subjects could take a rest after finishing one block. They were seated in a semidark room facing a monitor placed at 60 cm distance from the eyes, and were instructed to avoid blinking and eye movement of any sort and to keep their eyes fixated on the monitor during task performance and respond as fast and accurately as possible by pressing the corresponding button of the keyboard.

2.3. ERP Recording and Analysis

Brain electrical activity was recorded from 64 scalp sites using tin electrodes mounted in an elastic cap (Brain Products GmbH, Gilching, Germany), with the reference electrode on the left and right mastoids. The vertical electrooculogram (EOG) was recorded with electrodes placed above and below the left eye. All interelectrode impedance was maintained below 5 kΩ. The EEG and EOG were amplified using a 0.05–80 Hz bandpass and continuously sampled at 500 Hz/channel for offline analysis. Eye movement artifacts (blinks and eye movements) were rejected offline. Trials with EOG artifacts (mean EOG voltage exceeding ± 80 μV) and those contaminated with artifacts due to amplifier clipping, bursts of electromyographic activity, or peak-to-peak deflection exceeding ± 80 μV were excluded from averaging.

According to subjects' behavioral data, we mainly analyzed the ERP elicited by Successful mental imagery and Unsuccessful mental imagery responses (the ERPs were time-locked with the onset of Chinese oracle bone script). The averaged epoch for ERP was 2700 ms, including 2500 ms poststimulus and 200 ms prestimulus. Of course, only segments with corresponding responses (1 or 2 keys) were averaged, and at least 30 trials were available for each subject, condition. As observed in the grand averaged waveforms and topographical maps (see Figs. 2, 3), the ERPs elicited by Successful and Unsuccessful mental imagery conditions clearly differed from each other. The difference waves were obtained by subtracting the averaged ERP of Unsuccessful mental imagery from the averaged ERP of Successful mental imagery, and these differences were prominent over the frontal, central, parietal and occipital scalp regions. Thus, the following 20 electrode sites were selected for statistical analysis: Fz, FCz, Cz, CPz, Pz, Oz, AF3, AF4, F5, F6, C3, C4, CP3, CP4, TP7, TP8, P5, P6, O1, and O2 (these sites located in frontal, central, parietal and occipital scalp regions and were symmetric). The analyses of variance (ANOVA) factors were judgment type (Successful and Unsuccessful mental imagery) and electrode site (20 sites). For all analyses, p-value was corrected for deviations according to Greenhouse Geisser.

3. Results

3.1. Behavioral Performance

For Successful mental imagery and Unsuccessful mental imagery conditions, the average number of each judgment (Mean trials) was 70 ± 22 and 58 ± 22, and the average response times (RTs) were 413 ± 85 ms and 411 ± 102 ms when the signal "*" appeared. Repeated measures ANOVA for mean trials and RTs showed that there were no significant effect of judgment type [F (1, 13) = 1.14, $P > 0.05$; F (1, 13) = 0.03, $P > 0.05$].

3.2. Electrophysiological Scalp Data

The grand-average ERPs and topographic maps (Figs. 2, 3) showed the following spatiotemporal distribution for the ERP data. After onset of the stimuli, the N1, N2, P1, P2 and P3 were elicited by Chinese oracle bone script. Results of the ANOVAs showed that there were no main effect of judgment type for the amplitude and latency of N1, N2, P1, P2 and P3. Subsequently, Successful and Unsuccessful mental imagery both elicited a late positive component (LPC) after 600 ms. Mean amplitudes during the following time windows 600–1000 (LPC1), 1000–1500 (LPC2), 1500–2000, and 2000–2500 ms were analyzed using 2-way repeated measures ANOVAs.

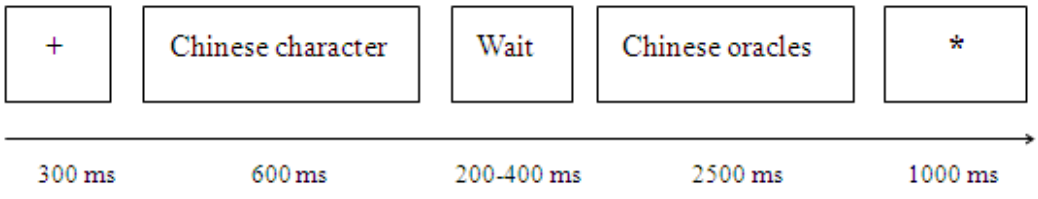


Figure 1. Timeline of stimuli, Chinese oracles were the target events to which Successful and Unsuccessful mental imagery judgments ERP data were time-locked, respectively

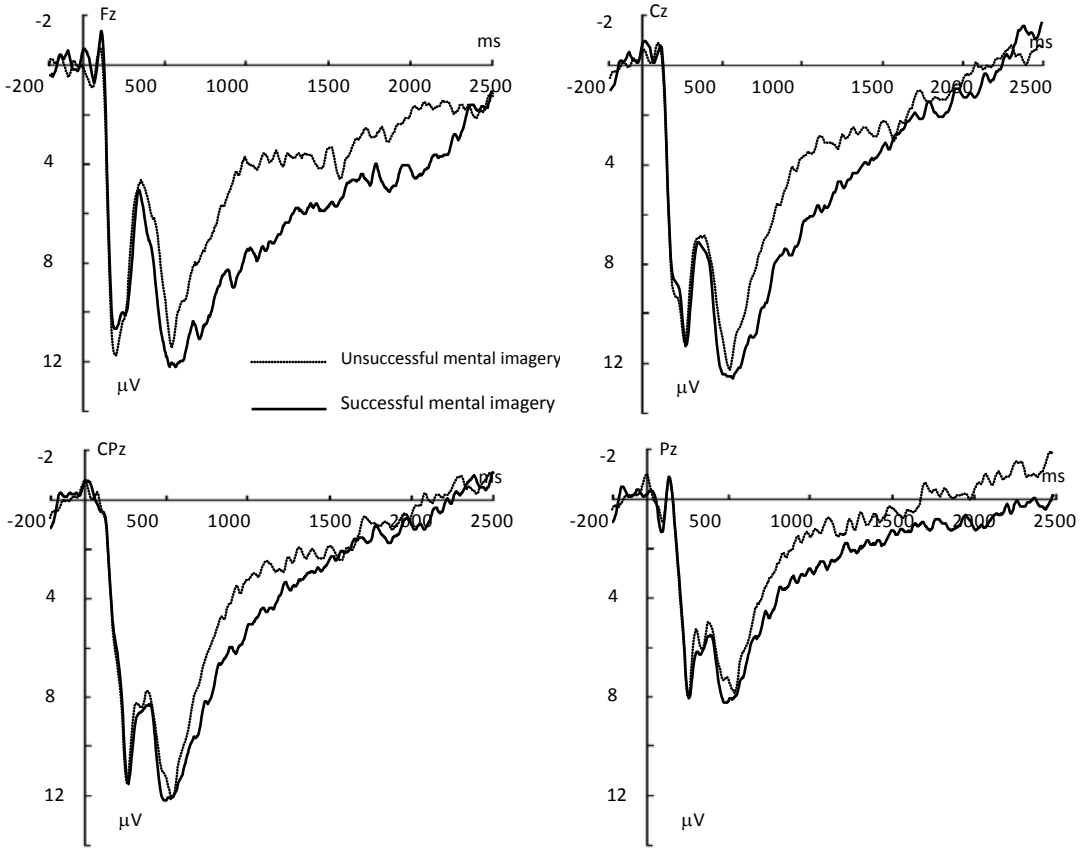


Figure 2. Grand average ERPs at Fz, Cz, CPz and Pz for two judgement types

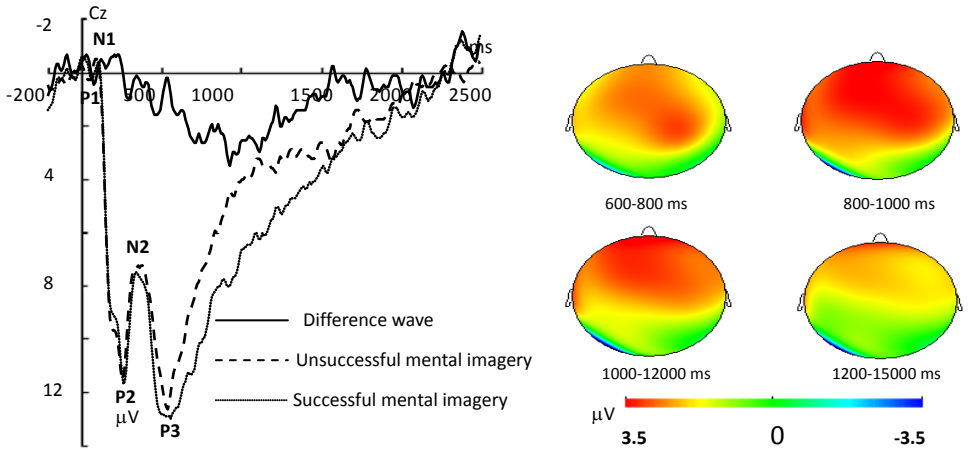


Figure 3. **Left:** Grand average ERP to Successful mental imagery, Unsuccessful mental imagery and the difference wave (Successful mental imagery - Unsuccessful mental imagery) at Cz. **Right:** Topographical maps of the voltage amplitudes for Successful mental imagery vs. Unsuccessful mental imagery difference wave in the 600–800 ms, 800–1000 ms, 1000–1200 ms and 1200–1500 ms

Main effect of judgment type was observed in the time windows of 600–1000 and 1000-1500 ms, F (1, 13) = 18.25, $P < 0.001$; F (1, 13) = 7.075, $P < 0.001$. It showed a greater positivity (LPC1: P600-1000; LPC2: P1000-1500) of Successful mental imagery as compared to Unsuccessful mental imagery. In addition, the interaction judgment type and electrode site was significant: F (19, 247) = 4.66, $P < 0.01$; F (19, 247) = 3.03, $P < 0.05$. Main effect of judgment type was not observed in the time windows of 1500–2000 and 2000–2500 ms, F (1, 13) = 1.82, $P > 0.05$; F (1, 13) = 1.94, $P > 0.05$. The interaction judgment type and electrode site was also not significant.

4. Discussion

In the present study, we used Chinese oracle bone scripts (the predecessor and prototype of Chinese Characters) as materials to explore the temporal course of brain processes underlying mental imagery. As for ERP waveforms, our results showed that there were no significant differences between Successful and Unsuccessful mental imagery for the amplitudes and latencies of N1, N2, P1, P2 and P3, which were the ERP components attributable to the early stage of feature selection and stimulus identification. It indicated that the early stage of mental imagery processing was almost the same under Successful and Unsuccessful conditions in the present study. Most importantly and interestingly, observing from the grand averaged waveforms and topographical maps, we found that the ERP components (LPC1 and LPC2) elicited by Successful mental imagery were obviously different from those by Unsuccessful mental imagery. We hereinafter discussed the implications of these ERP components in mental imagery processing.

First, Successful mental imagery elicited a more positive ERP deflection (LPC1: P600-1000) than Unsuccessful mental imagery in the 600–1000 ms time window. Maps of the difference wave (Successful-Unsuccessful mental imagery) showed strong activity over the fronto-central scalp regions, which was possibly related to forming visual mental imagery on the basis of initial stimuli classification and identification. Previous studies had indicated that the LPC might be the P300, which has been associated with many factors including stimulus evaluation, context updating, recognition memory, and task difficulty (Johnson, 1995; Kok, 2001; Polich & Kok, 1995). In general, P300 latency is thought to represent the relative duration of multiprocess stimulus evaluation/classification operations, and P300 amplitude reflects the amount of attentional resources employed in a given task (Donchin & Coles, 1988). West and Holcomb (2000) had found a bilateral LPC effect (in a time window of around 550–800 ms) to be most prominent in an image generation task compared to a semantic decision and a surface characteristics task. Recently, Kanske and Kotz (2007) also indicated that an interaction of emotion and concreteness on the LPC suggested that emotion and concreteness interact during processing of mental imagery. Thus, in the present study, the P600-1000 might reflect forming visual mental imagery of Chinese oracle bone scripts under Successful mental imagery condition.

Subsequently, a greater slow positivity (LPC2: P1000-1500) in Successful mental imagery as compared to Unsuccessful mental imagery was detected over the frontal scalp regions in the time window of 1000-1500 ms. As early as 1993, Smith (1993) had found that LPC might be related to word reconstruction and retrieving which was based on long-term memory system. Kusak et al. (2000) also found that the LPC amplitude increased as task difficulty increased, and suggested that the larger the processing demands to keep object information in working memory, the larger the LPC activity. Previous studies also suggested that slow waves in the ERP are correlated with rehearsal/retention operations in working memory (Ruchkin *et al.*, 1992; King & Kutas, 1995; Mecklinger & Pfeifer, 1996). Moreover, Finnigan et al. (2002) indicated that the amplitude of the LPC effect was sensitive to decision accuracy (and perhaps confidence) and its amplitude was larger in ERPs evoked by words attracting correct versus incorrect recognition decisions. In our study, subjects need maintain formed mental images in working memory and compare them with real objects or behaviors in order to make correct judgments. Therefore, we thought that the greater slow positivity (P1000-1500) might reflect maintaining mental imagery and making decisions in working memory.

In conclusion, our study compared spatiotemporal cortical activation patterns underlying Successful and Unsuccessful visual mental imagery of Chinese oracle bone scripts using ERP recording. The results showed that Successful visual mental imagery elicited a more positive ERP deflection (P600-1000 and P1000-1500) than unsuccessful mental imagery in the 600–1500 ms time window. We thought that these components reflected forming and maintaining visual mental imagery on the basis of initial stimuli classification and identification and making decisions in working memory.

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Stimuli Appendix



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