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Event-Related Potentials Analysis on Perception of Moving Object at Different Speeds

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Abstract: For this research, electroencephalography (EEG) was analyzed to investigate the perception ability of the brain for moving objects at different speeds. In this experiment, total six kinds of videos regarding license plates were created, moving at distinct speed of 0.26 m/s, 0.36 m/s, 0.46 m/s, 0.56 m/s, 0.66 m/s, and 0.76 m/s, respectively. In the semantic priming paradigm, the N400 effect was analyzed for each speed. The ERP results demonstrated that the N400 amplitude gradually reduced with increasing speed. At the three lower speeds, N400 was evoked evidently and mainly distributed in the centro-posterior region. At the three higher speeds, no significant N400 effect was found. The results concluded that the perception ability of the brain declined with the acceleration of the object's moving speed and that the brain recognized the detailed information of the moving object when its speed was lower than 0.46 m/s.

Key words: electroencephalography (EEG); N400; perception ability; moving object

1 Introduction

Every day, the brain needs to receive information in order to respond effectively to the external environment, more than 80% of which comes from visual perception. Therefore, the study of visual information processing is of great significance in revealing the cognitive mechanism of the human brain. Since it is difficult for the brain to recognize moving objects, more researchers are interested in its perception ability. In earlier Visual Evoked Potential (VEP) studies, N200 was found to be related to motion perception for human[1]. V1, V2, V3, and V5 areas in human are activated by the stimuli of coherent and incoherent motion[2]. Some studies focused on the Apparent Motion (AM) comprising of an individual object moving from one location to another at short/long range. It was found that the early visual cortex (V1) responded to the AM stimuli[3–5]. In addition, some researchers assessed the perception of motion in depth. Cottereau et al.[6] utilized functional MRI to investigate the spatiotemporal properties of the responses to lateral motion and motion-in-depth in the human visual cortex, and both responses appeared in the regions of interest: V1, V4, lateral occipital complex, V3A, and hMT+. Shen et al.[7] measured the perception ability of 3D moving stone's outline at different acceleration and the results demonstrated that 3 m/s was the limit of the human brain's perception of moving objects. However, few studies had focused on the perception ability of detailed information for moving objects, such as text content.

Event-Related Potential (ERP) is a specific electrophysiological response of the brain to external stimulus. Because of its advantages, such as high temporal resolution, phase-locking, and non-invasive detection, it is widely employed to study the cognitive activities of the brain in cognitive neuroscience and psychological science. N400 is one important negative component of ERPs that appears between 200 and

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600 ms post-stimulus onset and peaks around 400 ms. N400 is related to semantic incongruities in context[8–10]. As an objective electrophysiological index, N400 could be utilized to test the conflict of actions or movements[11, 12]. To illustrate, Proverbio et al.[13] found that skilled basketball players detected incorrect basketball movements and consisted more negative N400 components in comparison to non-players. Similarly, Orlandi et al.[14] found that compared with non-professional dancers, only professional dancers could react to the changes or abnormalities of dance movements and had a greater N400 effect in the middle of the parietal lobe. Therefore, the N400 could be employed as an evaluation index to measure the human brain's ability to recognize movements.

As aforementioned, the N400 effect was analyzed to explore the perception ability of moving objects. The semantic priming paradigm was designed to evoke the N400 effect. The written license plate numbers were used as prime stimuli, and the videos of license plates moving at six distinct speeds were taken as target stimuli. EEG and behavioral data were collected in the experiment. The N400 effect at six distinct speeds was evaluated using repeated-measures analysis of variance (ANOVA) to determine the perception ability of the brain.

2 Material and Method

2.1 Participants

Sixteen right-handed university students (9 males and 7 females, 22.75 ± 0.69 years old) participated in the experiment. All subjects had a normal or corrected vision with no recordings of neurological diseases and mental disorders. The study was conducted according to the Declaration of Helsinki and was approved by the local ethics committee. The subjects were requested to read and sign the researchers' consent form prior to the experiment and were financially awarded succeeding the research.

2.2 Materials

In this investigation, 480 videos of moving license plates were provided using Adobe Premiere software, and each video had a frame rate of 60 frames per second with a duration of 600 ms. The Chinese license plate usually has a blue background and seven white characters. The first character consists of an abbreviation of a province in China, and the last six characters are a combination of digits and letters. Forty written Chinese license plates were obtained as prime stimuli. These 480 videos of moving license plates were categorized into two groups as target and non-target stimuli that included inconsistent and consistent with the prime ones, respectively. Unlike the non-target license plate, four of the last five digits or letters of the target license plate were randomly changed. In order to ensure that all the changes were at the same level of difficulty, the following changes were avoided between target and non-target license plate numbers: from simple digits to simple ones (e.g., 0 to 1), from multi-digit discontinuous digits/letters to multi-digit continuous digits/letters, and from digits to letters, and vice versa. The videos included the license plates moving from the right side of the screen to the left one at six different speeds. In the duration of 600 ms, the speeds of license plates were accomplished by changing the moving distance. The screen had a size of 60 cm (length) $\times$ 35 cm (width) and pixels of 1920×1080. The pixels of each license plate were fixed at 440×140. According to the ratio of the length to the pixel of the screen, six distinct speeds of moving license plates in videos could be obtained as 0.26 m/s (Speed 1), 0.36 m/s (Speed 2), 0.46 m/s (Speed 3), 0.56 m/s (Speed 4), 0.66 m/s (Speed 5), and 0.76 m/s (Speed 6). Each speed condition comprised of 80 videos, including 40 consistent ones and 40 inconsistent ones. The difficulty level of different license plates at each speed was the same. For different speeds, 80 license plates were reused. For all videos, the speed of the same license plate was different. All videos were played in the center of the screen.

2.3 Experimental procedure

The experiment was conducted in an electromagnetic-shielding and sound-proof room. The subjects sat about 70 cm away from the screen in a comfortable posture. The refresh rate of the screen was 144 Hz. When the license plate moved from right to left on the screen, the subjects' gaze followed it. According to the law of cosines, the subjects' visual angles at six distinct speeds were 23.48°, 27.92°, 32.27°, 36.60°, 40.82°, and 44.94°, respectively. And the angular velocities corresponding to visual angles were 39.14°/s, 46.53°/s, 53.78°/s, 61.00°/s, 68.04°/s, and 74.89°/s, respectively.

In each trial of this experiment, the white cross "+" was first displayed for 200–300 ms in the center of the screen. Then, the written number of license plates lasted for 200 ms in the center of the screen. After the screen was blackened for 200 ms, a video of a moving license plate was played. Following this, the subjects were asked to judge whether the written numbers of the license plate and the numbers of moving license plates were consistent as soon as possible. If they were consistent, the left arrow key of the keyboard was pressed by the subjects. If inconsistent, the right arrow key was pressed. Finally, the screen was blank for 1000 ms and the next trial followed. A total of 480 trials were pseudo-randomized and categorized into six blocks. Each block consisted of 80 trials. The subjects rested for 3 to 5 minutes after each block. The whole experiment procedure is depicted in Fig. 1a. The movement route of the license plate during the target stage is illustrated in Fig. 1b, where A is the entry position on the right side of the screen and B is the exit position on the left side of the screen. A pre-experiment was conducted to ensure that subjects can be fully familiar with the experiment procedure during the formal experiment.

2.4 EEG recording

The EEG signals were recorded using the Neuroscan Synamps system with 64-channel Ag/AgCl electrodes. The electrodes were distributed according to the International 10–10 System. The sampling rate was 1000 Hz, and the right mastoid was used as an online reference point. The Horizontal electrooculography (HEOG) was collected through two electrodes on the outer canthi of both eyes, and the Vertical electrooculography (VEOG) was recorded from two electrodes above and below the left eye. The electrode impedance was kept below 5 kΩ during the experiment.

2.5 Data analysis

The raw EEG data were filtered by using a bandpass filter of 0.2–45 Hz. The average value of bilateral mastoids was taken as the offline reference. The EEG data was segmented from 200 ms before the video onset to 600 ms after the video onset, with the time window of 200 ms before video onset as the baseline. The epochs contaminated by ocular movements or other artifacts were eliminated manually, and the epochs with the amplitude exceeding the threshold of ± 100 μV were removed automatically.

Repeated-measures ANOVA was employed to evaluate the behavioral and ERP results. The Least Significant Difference test was conducted for pairwise analysis. All statistically significant effects were corrected using the Greenhouse-Geisser method.

3 Result

3.1 Behavioral results

The response time and recognition accuracy were analyzed in this experiment. The response time at six different speeds is illustrated in Fig. 2a. It was found that the response time evidently increased with the acceleration of the speed. Following this, the results of repeated-measures ANOVA demonstrated that there

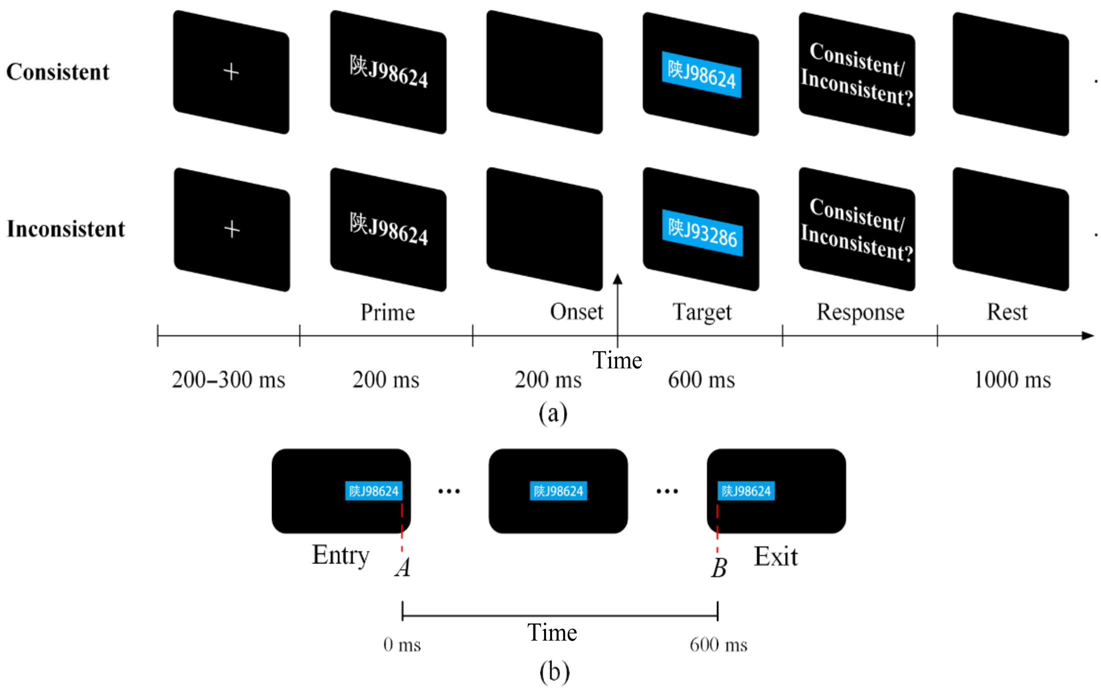

Fig. 1 Experiment procedure of moving objects, (a) experiment procedure and (b) movement route of license plate during target stage.

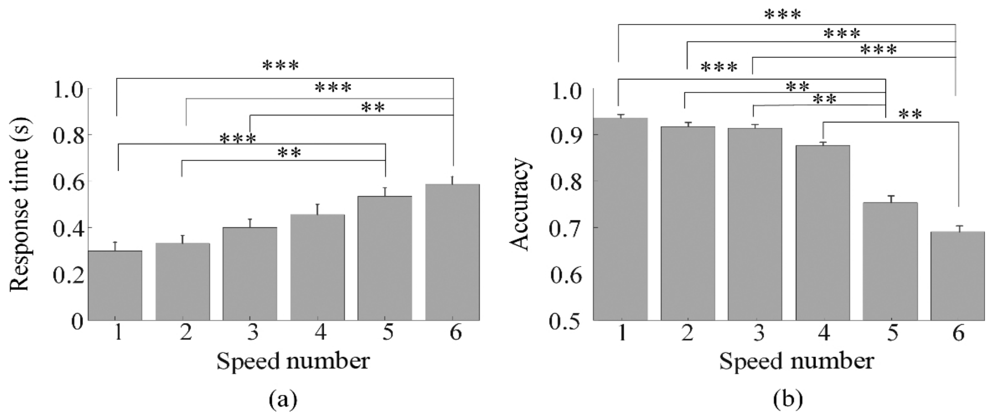

Fig. 2 Behavioral results, (a) response time and (b) accuracy. The error bars represent the Standard Error of the Mean (SEM). Statistical difference: * denotes $p<0.001$; ** denotes $p<0.01$; and * denotes $p<0.05$.**

was a significant difference in response time at different speeds ($F5, 90 = 5.459$, $p = 0.000$). The recognition accuracy is depicted in Fig. 2b. The recognition accuracy declined with the increase in speed. The results of repeated-measures ANOVA exhibited that there was a significant difference in the recognition accuracy among different speeds ($F5, 90 = 6.532$, $p = 0.000$). No significant differences in response time and accuracy were observed between Speeds 5 and 6. The results indicated that as the speed proliferated, the difficulty of cognitive tasks increased until it gradually reached saturation.

3.2 ERP results

The grand average of N400 amplitudes on the FCz, Cz, and CPz electrodes at six different speeds is displayed in Fig. 3a. The N400 effects of Speeds 1, 2, and 3 were evident in the time window of 250–400 ms, with Speed

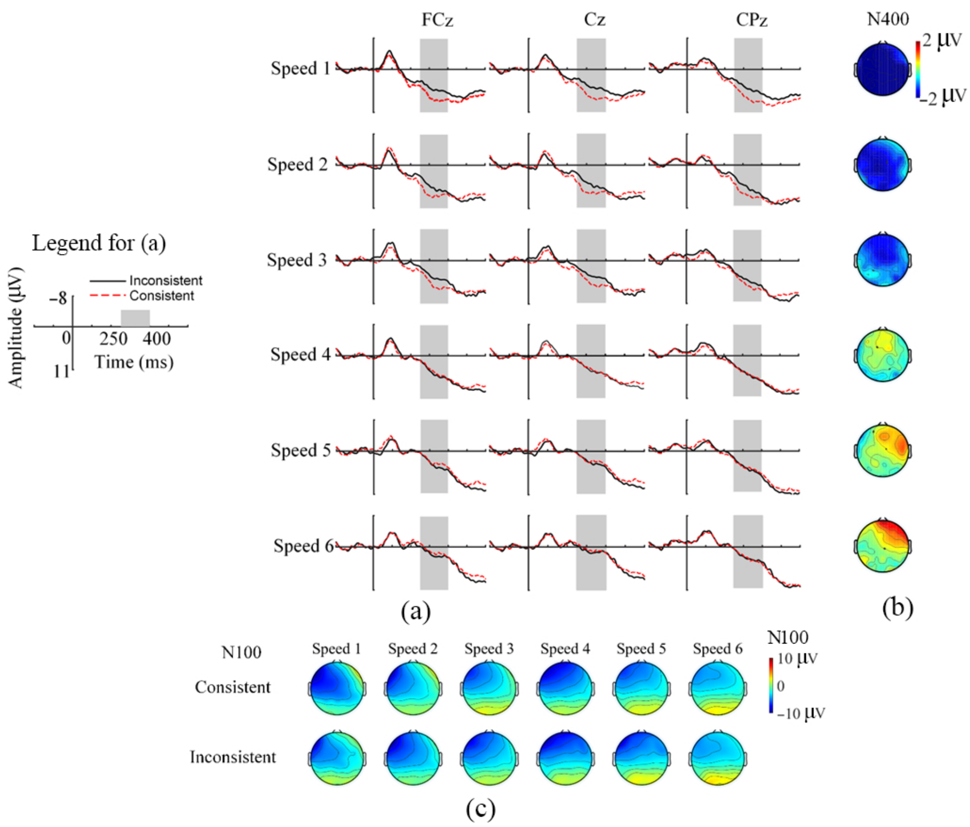

Fig. 3 ERP results, (a) the grand average ERPs on the FCz, Cz, and CPz electrodes at six different speeds, (b) topographic maps of N400 effects in the time window of 250–400 ms at six speeds, and (c) topographic maps of N100 components in the time window of 60–110 ms at six speeds.

1 exhibiting the strongest effects. However, no N400 deflections were observed at Speeds 4, 5, and 6.

For the time window of 250–400 ms, topographic maps of N400 effects at six distinct speeds are plotted in Fig. 3b[15]. It was shown that the N400 effects mainly concentrated in the centro-parietal region. The N400 effects were strong at Speeds 1, 2, and 3. And no evident N400 effects were evoked at Speeds 4, 5, and 6. To conclude, the N400 effect reduced with the increasing speed.

Additionally, the N100 component was evaluated. In Fig. 3a, large negative peaks of N100 components appear at about 100 ms for consistent ERPs and inconsistent ERPs at six distinct speeds. N100 component was induced by visual stimulation and related to the early processing of the visual cortex. As highlighted in Fig. 3c, the topographic maps of EEG data in 60–110 ms exhibit that the distribution of N100 is mainly concentrated in the left-frontal regions. No significant difference in N100 amplitude was found between consistent and inconsistent ERPs at different speeds.

Next, repeated-measures ANOVA of the N400 effects was analyzed in the centro-parietal region (FC1, FCz, FC2, C1, Cz, C2, CP1, CPz, and CP2, nine electrodes). The detailed results are illustrated in Table 1. The results showed that a significant difference in the N400 effect was observed among different speeds ($F5, 40 = 32.871$, $p = 0.000$). A pairwise follow-up analysis revealed that the N400 effects at Speeds 1, 2, and 3 were significantly higher than those at Speeds 4, 5, and 6 ($p < 0.05$) and that no significant difference in the N400 effect was obtained among Speeds 4, 5, and 6 ($p > 0.05$).

Table 1 Pairwise comparison results of N400 effect at six speeds.

	Speed 1	Speed 2	Speed 3	Speed 4	Speed 5
Speed 2	**0.029***	–	–	–	–
Speed 3	**0.000***	0.433	–	–	–
Speed 4	**0.000***	**0.000***	**0.000***	–	–
Speed 5	**0.000***	**0.000***	**0.000***	0.429	–
Speed 6	**0.000***	**0.000***	**0.000***	0.423	0.935

Additionally, the N400 amplitudes of the centro-parietal region at six distinct speeds are plotted in Fig. 4. The results showed that the N400 amplitudes declined with the increase in speed. The N400 effects at Speeds 1, 2, and 3 were strong and significantly higher than those at three lower speeds. The N400 effect at Speed 4 was weak, and no negativity was observed at Speeds 5 and 6.

As aforementioned, the N400 effects at three lower speeds were evident, and those at three higher speeds were weak or nonexistent. As the speed increased, the N400 effect diminished until it gradually disappeared. The results signified that Speed 3 was the threshold value of recognition to moving objects with detailed information.

3.3 Source localization

EEGLAB toolbox was exploited to localize N400 source[16]. The specific steps that were included in this process are as follows:

First, EEG data of Speed 1 were employed to localize the N400 source because the N400 effect at Speed 1 was significantly stronger than others. N400 waveforms were derived by subtracting the consistent waveforms from the inconsistent waveforms. The average N400 waveform of all trails for each subject was obtained.

Second, the SIM algorithm was conducted to decompose the ERP components using the N400 data of all subjects[17]. According to the ERP signal-to-noise

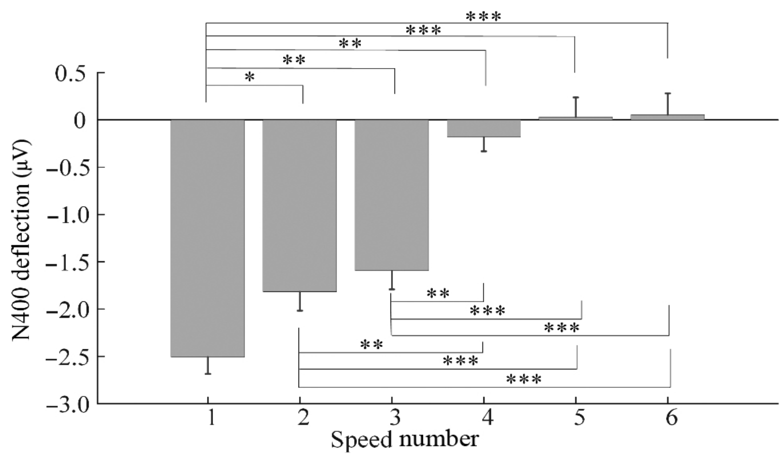

Fig. 4 N400 amplitudes at six speeds in centro-parietal region in the time window of 250–400 ms. The error bars represent the SEM. Statistical difference: * denotes $p<0.001$; ** denotes $p<0.01$; and * denotes $p<0.05$.**

ratio maximizer of the SIM algorithm, the first ERP component was selected as the N400 component. The negative peak of the first ERP component appeared at about 400 ms, and the spatial pattern corresponding to the first ERP component was mainly distributed in the centro-parietal region. The spatial pattern of the N400 component is shown in Fig. 5.

Third, the dipfit function of EEGLAB was employed to localize the N400 source with a single dipole. The input augments were spatial patterns of N400 components and N400 data of all subjects. For the dipfit-settings, the template of the boundary element model was selected as the head model with the threshold parameter set to 100% in multifit function. The N400 source localization is shown in Fig. 5. It unquestionably displays that the source of the N400 component is mainly in the left posterior-temporal cortex.

4 Discussion

4.1 Behavioral and ERP results

In the present study, the subjects' response time and recognition accuracy proliferated with the increasing speed of the moving license plate until they gradually reached saturation. It revealed that as the speed elevated, the difficulty of subjects' cognitive tasks correspondingly increased. In the ERP results, as the speed elevated, the N400 amplitude gradually reduced until it disappeared, correlating with behavioral results. It was found that the N400 effects at Speeds 1, 2, and 3 were strong and significantly higher than those at three lower speeds, with no significant difference found at Speeds 4, 5, and 6. It was indicated that Speed 3 was the limit of moving object recognition.

In the behavioral results of Speeds 4, 5, and 6, it took more than 500 ms approximately for the subjects to complete the response. Thus, wrong-key response, subjective judgment, and high-level processing of the human brain may be involved. Behavior results are subjective, uncertain, and inaccurate, while ERP results are objective, accurate, reliable, and fast. Therefore, it is necessary to analyze the cognitive ability among different speeds using the ERP method.

4.2 Perception of moving objects

This study illustrated that the speed of moving object recognition reached the limit, which was close to 0.46 m/s. The result was different from previous studies[7, 18, 19]. In Heinrich et al.'s study[18], VEPs to motion stimuli were recorded at five different conditions: static, low speed (3.5°/s) in the same or opposite direction, high speed (32°/s) in the same or opposite direction. The results showed that N2 amplitude was significantly different between high and low speed conditions. In Shishkin et al.'s study[19], the amplitude and latency of the ERP components were evaluated with the matrix that moved at different speeds (5°/s, 10°/s, and 20°/s). There was a significant difference for N1 but not for P300. In both studies, the stimulus patterns rotated leftward or rightward at different speeds, following which the perception of rotational motion for the brain was analyzed. In Shen et al.'s study[7], the motion-in-depth perception of five movement patterns was investigated, and N310, N480, as well as N810 of ERPs were analyzed. The result showed that the speed of 3 m/s was the threshold of perceiving the outline of a moving object. In comparison to previous studies, this study focused on the recognition of detailed information in moving objects; thus, a slower speed was needed for the brain. In the study, the changes of license plate moving at 0.46 m/s could be recognized. And more detailed information of moving objects could be effectively recognized when the speed was less than 0.46 m/s. This study proves as the further extension of previous studies.

The semantic inconsistency of moving objects could evoke the N400 effect. As found in studies of Refs. [13, 14], professional basketball players or professional dancers demonstrated a greater N400 effect than non-professionals when they watched inaccurate or abnormal movements. These studies are in line with the current conclusion. Inspired by it, this investigation employed the semantic priming paradigm and N400 effect to evaluate the human brain's recognition ability of detail

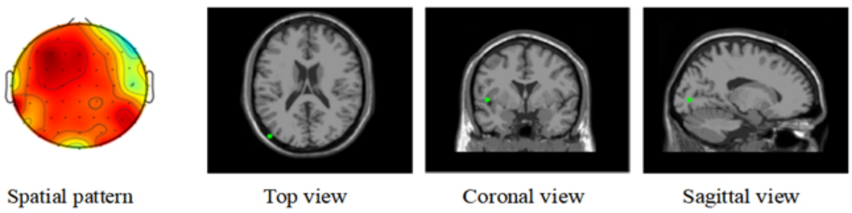

Fig. 5 Spatial pattern and source localization of N400 component.

information of moving objects at distinct speeds.

4.3 Source localization analysis

In this study, the source localization analysis using EEGLAB illustrated that the source localization of the N400 component was in the left posterior-temporal cortex, which was consistent with some previous studies. The fMRI study about N400 proposed that the N400 source was localized in the left Middle Temporal Gyrus (MTG), bilateral anterior cingulate, anterior Left Inferior Prefrontal Cortex (aLIPC), and posterior LIPC (pLIPC) regions[20]. The MEG studies showed that the N400 component of the time window of 250–500 ms was mainly distributed in the temporal cortex region[21–23], and semantic anomaly about the time window of 200–400 ms in the EROS study exhibited that N400 was mainly related to the regions of left MTG and left occipitotemporal cortex[24]. Therefore, it was rational in this study that the source localization of the N400 component related to the identification of moving objects was mainly in the left posterior-temporal cortex regions of the brain.

4.4 Application

In this study, the N400 component was analyzed based on the semantic priming paradigm, which was more objective and accurate than subjective measurement using self-report questionnaires. In future applications, the experimental results might provide a valuable reference for character recognition in driving, words recognition in video playing, and object recognition in other moving scenes.

N400 plays an important role in the studies of clinical neuropsychological diseases such as Alzheimer's disease, dyslexia[25], epilepsy[26], autism, aphasia, cerebral palsy, and hypoxia brain injury[27]. In the future, the results of this study can prove to be beneficial to the auxiliary diagnosis of the above diseases.

5 Conclusion

This study investigated the brain's ability to perceive objects moving at different speeds. With the acceleration of speed, both the N400 amplitude and the brain perception ability decreased. The brain could recognize detailed information of moving objects at a speed of less than 0.46 m/s.

Acknowledgment

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