ORIGINAL ARTICLE

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Changes in the somatosensory N250 and P300 by the variation of reaction time

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Abstract We investigated the relationship between somatosensory event-related potentials (ERP) and the variation of reaction time (RT). For this purpose, we recorded the ERPs (N250 and P300) in fast- and slowreaction trials during a somatosensory discrimination task. Strong, standard, and weak target electrical stimuli were randomly delivered to the left median nerve at the wrist with a random interstimulus interval (900-1,100 ms). All the subjects were instructed to respond by pressing a button with their right thumb as fast as possible whenever a target stimulus was presented. We divided all the trials into fast- and slow-RT trials and averaged the data. N250 latency tended to be delayed when the RT was slow, but not significantly. P300 latency was delayed significantly when the RT was slow, but to a much lesser extent than the RT delay, so we concluded that the change of RT was not fully determined by the processes reflected by the somatosensory N250 or P300. Furthermore, the larger and earlier P300 in the fast-RT trials implied that when larger amounts of

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Division of Health and Sports Education, United of Graduate School of Education, Tokyo Gakugei University, Tokyo, Japan attentional resources were allocated to a given task, the speed of stimulus evaluation somewhat increased and RT was shortened to a great extent. N250 amplitude did not significantly vary in the two RT clusters. In conclusion, the somatosensory N250 reflects active target detection, which is relatively independent of the modulation of the response speed, whereas the somatosensory P300 could change without manipulation of either the stimulus or the response processing demand.

Keywords Attention · N250 · P300 · Somatosensory · Reaction time

Introduction

Reaction time (RT) is one of the important measures in understanding the sensorimotor performance in humans (Schmidt 2000) and is commonly defined as the time elapsing between the onset of a stimulus and the initiation of a response (Posner 1978). The RT can also be broken down to include components such as stimulus evaluation, response selection, and response execution (Doucet and Stelmack 1999). Many studies have reported on the relationships between the RT and some components of event-related potentials (ERPs) during several discrimination tasks. For example, studies concerning vision include: (P3) Kutas et al. 1977 and (N2) Ritter et al. 1979; ones concerning audition include: (N2) Novak et al. 1990, and Titiinen et al. 1994. However, most of these varied the stimulus processing demand or discriminability. Moreover, the relationship between the RT and somatosensory ERPs has been investigated in less detail than in the other modalities.

In active oddball or discrimination situations, infrequent somatosensory deviant (target) stimuli elicit the N250-P300. It may be considered that the somatosensory N250 is analogous to auditory N2b or visual N2 (Ito et al. 1992) and it is elicited by deviant stimulus only when subjects attend to it (Kekoni et al. 1996). Other researchers have also reported that the N250 was elicited when the deviant stimulus was task-relevant (Jossiasen et al. 1982; Kujala et al. 1995). In contrast, Ito et al. (1992) and Kekoni et al. (1997) found a small N250-like wave in response to the task-irrelevant stimulus, which the subjects were instructed to ignore, but this was caused by the attentional capture, i.e., the involuntary shift of attention to the task-irrelevant stimulus (Kekoni et al. 1996, 1997). Thus, previous studies have indicated that the N250 reflects conscious target detection (Kekoni et al. 1996) in an attentive process.

P300 is well known to be representative of the endogenous ERP component and is considered to be elicited irrespective of sensory modality. Theoretically, the P300 is believed to index the brain activity required in the maintenance of working memory when the mental model of the stimulus environment is updated (Donchin and Coles 1988). Its amplitude reflects the amount of attentional resource devoted to a given task (Wickens et al. 1983; Kramer and Strayer 1988; Kok 1997, 2001). The P300 latency is considered a measure of stimulus evaluation time and is generally unrelated to response selection and execution (Kutas et al. 1977; McCarthy and Donchin 1981; Pfefferbaum et al. 1983; Verleger 1997). This claim is based on the following observation. When stimulus evaluation demands are increased, both RT and P300 latency tend to increase. But, when response processing demands are increased, RT is often the only measure that increases (Doucet and Stelmack 1999). The term "stimulus evaluation" does not necessarily imply that the subject has fully extracted all the relevant task information. For example, it is conceivable that in conditions that create a data limitation (such as low perceptual quality of the stimulus or high time pressure) or when the subject follows a strategy that favors speed above accuracy, P3 can also be emitted on the basis of partial information (Kok 2001). Despite these detailed investigations of P300, there have been few reports that demonstrated whether or not the somatosensory P300 changes without external manipulation of the stimulus or response processing demand.

The purpose of the present study was to examine the relationship between the ERP components and the variation of RT during the oddball paradigm, in which both stimulus and response processing demands were not manipulated by the experimenter. So, we divided all the trials into fast- and slow-RT trials in order to obtain two kinds of ERPs. This procedure allowed us to investigate whether or not the RT, N250 and P300 could change without manipulation of stimulus and response processing demand.

Methods

Subjects

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The stimuli were delivered to the left median nerve at the wrist while the subjects were sitting comfortably in an electrically shielded room. The interstimulus interval (ISI) varied randomly between 900 and 1,100 ms (mean 1,000 ms). A total of 1,500 stimuli were delivered. Selection of the median nerve as the stimulus site allows us to biocalibrate the stimulus intensity. The intensity of the standard stimulus (80%) delivered to the nerve was estimated by monitoring the M-wave magnitudes at approximately 80% [2.83 (± 0.23)×sensory threshold] of the maximal M-wave (M_{max}), resulting from direct stimulation of motoneuronal axons; that of the target stimulus (20%) was 10% of the M_{max} [2.34 (± 0.18) ×sensory threshold]. The M-wave was monitored on an oscilloscope throughout the experiment so that any change in the stimulus intensity could be observed. This common technique for biocalibration of stimulus intensity (Misiaszek et al. 1995; Stains et al. 1997) is supported by neurographic studies that reveal a strong correlation between M-wave amplitudes and afferent volleys (Fukoshima et al. 1982; Abbruzzese et al. 1985;). However, we rarely had to adjust the physical intensity of the target and standard stimulus during recordings, owing to the stability of the M-wave magnitude. Standard and target stimuli were presented in a pseudorandom order. The subjects' ability to discriminate deviant from standard stimuli was ascertained before the experiment began.

Task

Stimuli

The subjects were instructed to respond by pressing a button with the right thumb as fast as possible whenever a target stimulus was presented. The duration of an experiment was about 40 min, excluding the recording preparation.

Recordings

The electroencephalography (EEG, 0.5–500 Hz) was recorded with Ag/AgCl electrodes from five scalp locations: Fz, Cz, Pz, C3, and C4. All the scalp electrodes were referred to linked earlobes and impedance at all EEG recording sites was less than 5 k Ω . The electro-oculogram (EOG) was recorded bipolarly from the right outer canthus and the suborbital region to monitor eye movements or blinks. The compound muscle action potential (M-wave) was recorded over the flexor pollicis brevis of both hands. The analysis period was 800 ms including a 100-ms prestimulus baseline. RT and electromyographic reaction time (EMGRT) were measured between 150 and 700 ms after the onset of the target stimulus. Mechanical time (MT) was defined as the interval between EM-GRT and RT. Trials with eye blinks, eye movements (rejection level: $\pm 100 \ \mu$ V) and response errors were excluded from analysis. The sampling rate of analog-digital transformation was 1 kHz.

Analysis

First, we divided the raw EEG data into fast- and slow-RT trials according to the RT, and then averaged them separately. The criterion for the classification was the median value of the individual RT. Thus, ERPs for both the fast- and slow-RT trials were obtained.

The N250 and P300 peak amplitudes, which were determined from individual ERPs, were measured from time windows of 180– 280 ms and 250–500 ms after stimulus onset, respectively. The N250 and P300 latencies were determined as a time from stimulus onset to their peak point. The analysis was performed on the average ERP, not on the single trial ERPs. For the peak amplitude data, two-factor analysis of variance with repeated measures was performed [response speed (2) × electrode (5)]. The reported significances for the F values were those obtained after Greenhouse-Geisser correction, when appropriate, and then a correction

Seven healthy right-handed subjects (aged 22–29 years; six males, one female) participated in the experiment. No subjects reported any neurological or psychiatric problems and gave informed consent.

coefficient ε was given. Significance was set at P < 0.05. For the analysis of EMGRT and MT, the two-tailed paired *t*-test was used. The number of trials that were excluded due to EOG contamination was 76.57 (\pm 39.22), the number of response errors was 16.86 (\pm 2.49), and the number of trials that entered the final analysis was 206.57 (\pm 40.78).

Results

Performance

Mean RT was 404.71 ms in the fast-RT trials, whereas it was 511.48 ms in the slow-RT trials. The difference between the fast- and slow-RT trials was about 100 ms. Mean EMGRT was 323.88 ms in the fast trials and 415.05 ms in the slow trials. The difference between them was approximately 90 ms and was significant (P < 0.001). Mean MT was 80.93 ms in the fast trials, whereas it was 88.60 ms in the slow trials. The difference between them was not significant (P=0.24).

Event-related potentials

Fig. 1 shows the grand average waveforms of ERPs in response to target stimuli, and Fig. 2 shows the amplitude. The ERPs were clearly different between fast and slow RT. Visually, it was evident that the P300 amplitude was smaller when the RT was slow, as opposed to fast. This was supported by a significant main effect of response speed [F(1,6) = 41.450, P < 0.01]. Furthermore, an interaction between response speed and electrode was also obtained [F(4,24) = 13.849, P < 0.001] suggesting that the increase in P300 amplitude occurred largely over

Fig. 1 Grand average waveforms for the fast- and slow-reaction time (*RT*) trials at each electrode site. *Lower squares* show the mean RT across all the subjects



Fig. 2 Mean N250 and P300 amplitude values for the fast- and slow-RT trials at each electrode site

the parietal area. In addition, a main effect of the electrode showed that the distribution of P300 was parietaldominant in both the fast- and slow-RT trials [F(4,24) = 7.012, P < 0.01]. The P300 latency was significantly earlier when the RT was fast, compared to when it was slow [F(1,6) = 12.015, P < 0.05].

Response speed did not affect the N250 amplitude [F(1,6)=0.054, P=0.825]. Although the N250 latency tended to be earlier when the RT was fast, as opposed to slow, no significant difference was obtained [F(1,6)=3.8, P<0.099]. In addition, an interaction between response speed and electrode was not significant [F(4,24)=1.603, P=0.243, $\varepsilon=0.475$].

The difference in the N250 latency between the fastand slow-RT trials was 24 ms and in the P300 latency it was 23 ms. These differences were generally smaller than that obtained for the EMGRT (90 ms). In the fast



trials the EMGRT was 50 ms earlier than the P300 latency, whereas in the slow trials it was 25 ms later.. The N250 latency was 80 ms earlier than the EMGRT in the fast trials and was 140 ms earlier in the slow trials (Fig. 3).

Discussion

In the present study, N250 latency and amplitude were not affected by variations in RT in an oddball paradigm. Therefore, it was considered that the N250 was relatively independent of this RT variation.

Previous studies reported that N250 was not elicited in an ignore task but was in active attention tasks (Kekoni et al. 1996). Therefore, it has been considered that the somatosensory N250 reflects active target detection in an attentive process (Kekoni et al. 1996). Some previous results have supported this hypothesis (Jossiasen et al. 1982; Ito et al. 1992; Kujala et al. 1995; Kekoni et al. 1997). Thus, the present study may indicate that this attentive process is not directly related to the processes that determine the variation of RT.

The P300 amplitude and latency changed between the fast- and slow-RT trials. In particular, the modulation of P300 amplitude was dominant over the parietal area, suggesting that this was mainly caused by the P3b. The P300 amplitude was larger when the RT was fast, implying that when more attentional resources were allocated to the given task the motor outputs were faster. It has been suggested that the stimulus evaluation time is faster when more attention is allocated; however, since the P3 latency was delayed when the RT was slow, albeit to a much lesser extent than the RT delay, we concluded that the variation of RT was not fully determined by the change in the P300 latency.

On the other hand, the N250 and P300 showed different modulations depending on the response speed.



Fig. 3 Mean RT, EMGRT, mechanical time (MT), N250 latency (Cz), and P300 latency (Pz) values for the fast- and slow-RT trials

This result may suggest there are somewhat functional differences between these ERP components. In general, the auditory N2b or visual N2 is usually followed by a P3 deflection, and therefore they are often called the N2–P3 complex (Näätänen 1992; Kekoni et al. 1996). The N2–P3 association is strong but the N2 can also occur without the P3 (Knight 1990; Ritter et al. 1992), and vice versa (Sams et al. 1985). Therefore, even if the behavior of N250 differed from that of P300 it is not so surprising because the somatosensory N250 may be analogous to the auditory N2b or visual N2 (Ito et al. 1992; Kekoni et al. 1996).

The N2 and P3, elicited by visual or auditory target stimuli, involved several intracranial generators (Smith et al. 1990; Baudena et al. 1995; Halgren et al. 1995a, 1995b, 1998; Clarke et al. 1999) whereas multiple cerebral regions contributed to the somatosensory P300 (Bruyant et al. 1993; Tarkka et al. 1996), thus supporting the hypothesis of a large neuronal network contributing to P300 generation. Recently, Valeriani et al. (2001) reported that two dipole sources located bilaterally in the medial temporal region and a frontal dipole contributed to the generation of somatosensory P300. In contrast, the cerebral generators of the somatosensory N2 (N250) still remain unknown and, therefore we cannot assume differences between the N250 and P300 generators. However, if the previous results in the auditory and visual modalities can be applied to the somatosensory modality, the generator processes of N250 may be found to be somewhat different from those of P300.

According to transcranial magnetic stimulation (Rothwell et al. 1991) and MEG (magnetoencephalography)/EMG coherence studies (Gross et al. 2000), the delay from cerebral motor drive to onset of muscle activation was about 23 ms in the case of hand muscle (e.g., interossei dorsales). In the fast trials of the present experiment, therefore, it may be considered that the cerebral motor command to the muscle was output before all relevant information was fully extracted. On the other hand, because P300 latency was 25 ms earlier than the EMGRT in the slow-RT trials, after larger amounts of relevant information were processed the cerebral motor command might be output for the muscle activation. These findings indicate that when more attention is allocated to the task, the speed of the stimulus evaluation is slightly increased and the motor command might be output even if all the relevant information has not been fully processed.

In conclusion, the somatosensory N250 reflects an active target detection that is relatively independent of variation in the response speed. On the other hand, the somatosensory P300 can be changed without the manipulation of either the stimulus or the response processing demand.

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