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A PSYCHOPHYSIOLOGICAL STUDY OF AUDITORY ACCESSORY EFFECTS ON RESPONSE EXECUTION AND INHIBITION[1]

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This study examined effects of the auditory accessory stimulus that was irrelevant to the task by using event related potentials (ERPs). The P300 and the lateralized readiness potential (LRP) were recorded concurrently to monitor the changes of covert processes. The former considered to reflect the duration of the stimulus evaluation, and the latter could be a real-time index of hand specific motor preparation. Ten subjects engaged in a Go/NoGo task accompanied by the auditory accessory. The accessory caused following three changes on ERP measures; the reduction of the P300 latency, the augmentation of the NoGo-P300 at Fz and Cz, the negative deflection of the LRP. These results manifested that the accessory partially initiated the subjects' movement preceding the imperative stimulus.

Key words: auditory accessory stimulus, P300, lateralized readiness potential, Go/NoGo task.

INTRODUCTION

Processing in modalities are not independent of each other. They are influenced by concurrent activity in other modalities (Welch & Warren, 1986). For example, the reaction time (RT) to a visual stimulus can be shortened if an auditory stimulus is presented simultaneously. This intersensory facilitation takes place even when subjects are instructed to ignore the auditory stimulus (Bernstein, Clark, & Edelstein, 1969). In such a bimodal stimulation task, the auditory stimulus is called "accessory" in the sense that subjects need not attend to in order to perform the task. Two models have been suggested to account for the effect of the auditory accessory stimulus (Bernstein, 1970; Nickerson, 1973). First, an energy summation across sensory modalities caused stronger energy about the imperative stimulus. Second, the accessory reduced the distance to the motor output by enhancing the readiness to respond. The former is called energy summation model, and the latter is preparation enhancement model. These two models have been developed by RT studies on the basis of Sternberg's (1969) additive factor methods (Schmidt, Gielen, & Van den Heuvel, 1984; Keuss, Van der Zee, & Van den Bree, 1990). Although these studies suggested significant evidence for the accessory effects, measures of overt responses as RTs cannot monitor covert processes that exist between the stimulus input and the response output. Thus, it has been impossible to assess directly whether the accessory facilitate the processing of the imperative

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stimulus or enhance the response preparation.

This study used electrophysiological measures to observe changes of covert processes evoked by the accessory stimulus. Two components of event related potentials (ERPs) are useful tools for that perpose. First is the P300 whose latency indicated the duration of stimulus evaluation (Kutas, McCarthy, & Donchin, 1977; Duncan-Johnson, 1981). Recently, Nakano and Maruyama (1993) recorded the P300 component in a visual choice reaction time task accompanied by the auditory accessory stimulus. They found that the accessory shortened not only the RT but also the peak latency of the P300. So they inferred that the accessory facilitated the evaluation of the imperative stimulus by serving as a supplemental warning signal. Although this inference seems to support the energy summation model, the preparation enhancement can also explain the reduction of the P300 latency. For example, the P300 could be elicited when subjects initiated the response to the accessory stimulus.

The lateralized readiness potential (LRP) manifests the changes of the preparatory states for a movement (Coles, 1988). The LRP is based on the Readiness Potential (RP) that emerges preceding voluntary movements (Vaughan, Costa, & Ritter, 1968). Some time before the movement onset, the RP starts to lateralize with larger amplitudes above hemisphere contralateral to the movement hand (Barret, Shibaseki, & Neshige, 1986). The LRP is the difference between the amplitudes of the RP over the right and left cerebral hemisphere. It's deflection from the base line indicates the activation of motor related areas contralateral to the movement side. This characteristic of the LRP serves to monitor the specific response preparation for either hand (Gehring et al., 1992; Gratton et al., 1990). If the accessory stimulus activates the response preparation process, it should be reflected by the LRP.

The task and the stimulus arrangement must be selected carefully in recording the LRP. In the choice reaction task as Nakano & Maruyama (1993), subjects can not prepare the response hand before an imperative stimulus is presented. As a result, the LRP does not deflect before the stimulus. To let subjects prepare the response preliminary, it must be assigned to either hand. Thus this experiment adopted the Go/NoGo task which required subjects performing a right hand movement (Go) or withholding it (NoGo). Furthermore, the LRP should not be contaminated by components that were irrelevant to the response preparation. To extract the movement related component alone, the stimuli that are presented subjects must bring equal activation over the both hemisphere. So the auditory stimulus presented binaurally, and the visual stimuli arranged vertically.

METHOD

Subjects: Ten volunteered students whose ages ranged from 19 to 27 years participated in one practice and two days of an experimental session. All subjects were males and right handed, and they had normal or corrected-to-normal vision.

Stimuli: Visual stimuli were three light emitting diodes (LEDs) that were located vertically. The middle red LED served as the fixation point, it's luminance was 10 cd/m^2. The upper and the lower green LED served as the imperative stimulus (IS). Their luminance was 5 cd/m^2. They were distant 1 cm above and below from the fixation point. Subjects observed the sets of visual stimuli apart from 50 cm. The 80 dB SPL, 1000 Hz pure tone stimulus was used as a warning stimulus and an accessory stimulus. These stimulus were presented binaurally via headphone.

Procedure: At the starting of each trial, the auditory stimulus was delivered for 200 msec as a warning signal. Following this, the fixation point appeared at the center of the subjects' eye field. After a foreperiod varied from 1200 to 2000 msec, the IS was presented for 50 msec either above or below the fixation point. Half of the subjects were instructed to press the key quickly if the LED was presented above the fixation point (Go stimulus), and withhold the response if the LED was presented below (NoGo stimulus). The other subjects were inversely assigned the Go and NoGo stimuli. The Go and NoGo stimulus occurred with relative frequencies of 80 % and 20 %. In half of Go and NoGo trials, the auditory accessory stimulus was presented for 80 msec preceding the IS by 300 msec. The subjects were told that they could ignore the tone. The presence of the tone was randomized across trials. The fixation point disappeared 1500 msec after the IS to inform the subjects the end of the trial. After an interval of 2000 msec the next trial started. The subjects took part in two experimental sessions, one on each of two separate days. The session consisted of 11 blocks, each contained 40 trials. The first block devoted to practice. The whole 800 trials included 640 of Go trials and 160 of NoGo trials. In each of the response types, the auditory accessory was presented on half of the trials.

Psychophysiological recordings: EEG was recorded at Fz, Cz, Pz, according to the 10/20 system, by using Ag-AgCl electrodes referenced to right ear-lobe. The LRP derived bipolary from C3' (4 cm left to the Cz)-C4' (4 cm right to the Cz). The EEG signals amplified by bioelectric amplifier (MEG2100-Nihon Kohden) with the time constant of 5 sec and the high-cut of 100 Hz. To check the contamination of artifacts, the vertical EOG was recorded from electrodes above and below the right eye. The EEG and EOG data were digitized at 200 Hz for 2100 msec, starting 600 msec before the IS. They were stored by a computer (NEC:PC-9801RX) for off-line analysis.

Data processing: Trials having erroneous responses or contaminating artifacts, as eyemovements, were excluded from further analysis. A linear trend component was removed from each single EEG data. Stimulus-synchronized average waveforms were constructed for each of the conditions and electrodes separately. These were digitally smoothed with a rectangular moving window of 200 msec to attenuate the high-frequency components superimposed on ERPs.

RESULTS

Following trials were considered as an error; the RT was above 400 msec or below 100 msec, the key pressing was made to the NoGo stimulus. These trials excluded from further analysis. The mean RTs obtained on correct trials were 294 msec for non-accessory trials and 252 msec for accessory trials. These data were submitted to one-factor (accessory vs non-accessory) analysis of variance (ANOVA). The results showed that the accessory shortened the RT, $F(1,9) = 61.39$, $p < .01$.

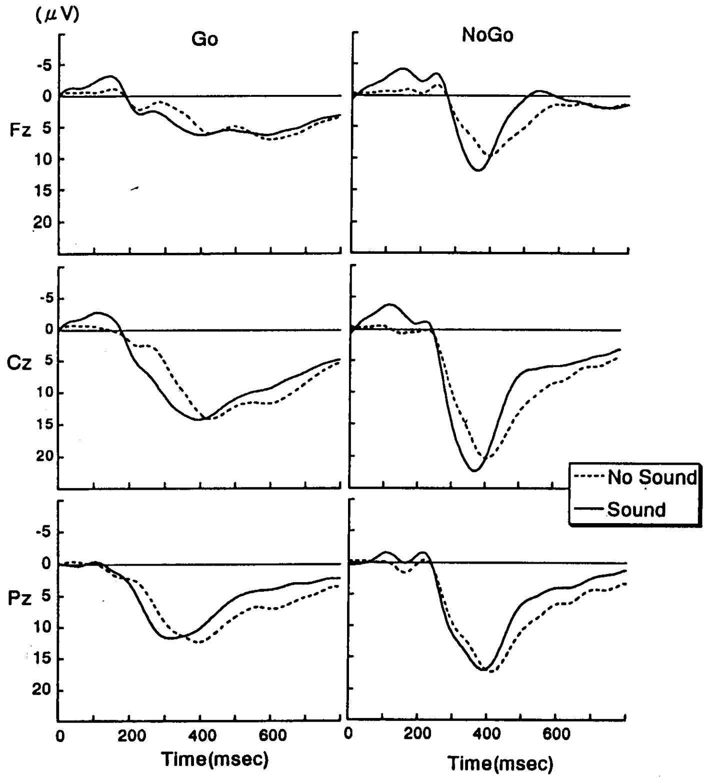

Fig. 1. Grand average of stimulus-synchronized ERPs with accessory (sound; solid line) and without accessory (no sound; dashed line) conditions at Fz, Cz, Pz. The left waveforms are on go trials and the rights are on NoGo trials.

P300: Figure 1 shows average waveforms at Fz, Cz, Pz referred to a 100 msec pre-IS base line for each conditions and response types. The peak latency of the P300 was identified as the maximum point between 200 msec and 600 msec after the IS. The voltage value of this point was taken as the P300 amplitude. Figure 2 and 3 showed mean P300 latencies and amplitudes for each conditions respectively. The measures of the P300 latency and amplitude were submitted to a $2 \times 2 \times 3$ (accessory $\times$ response type $\times$ electrode site) repeated measures of ANOVA. The analysis showed that the accessory shortened P300 latency regardless of response type at every electrode site, $F(1,9) = 36.59$, $p < .01$. There was a two-way interaction about response type $\times$ electrode. Multiple comparisons showed that the P300 latency was shorter at Pz than Fz on Go trials, and this relationship was inverted on NoGo trials (Fz $<$ Pz). On the other hand the P300 amplitude was larger on NoGo trials than on Go trials, $F(1,9) = 14.5$, $p < .01$. On NoGo trials, the accessory augmented the amplitude at Fz and Cz (Fig. 3). That should cause the significant three-way interaction,

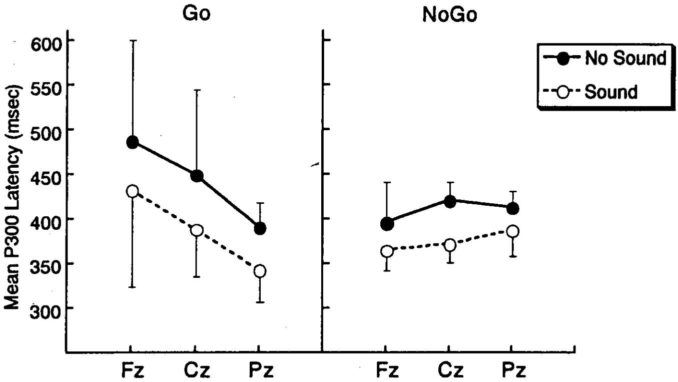

Fig. 2. Mean P300 latencies at Fz, Cz, PZ on Go (left) and NoGo (right). The open circle indicates the non-accessory (No Sound) condition, and closed circle is the accessory (Sound) one.

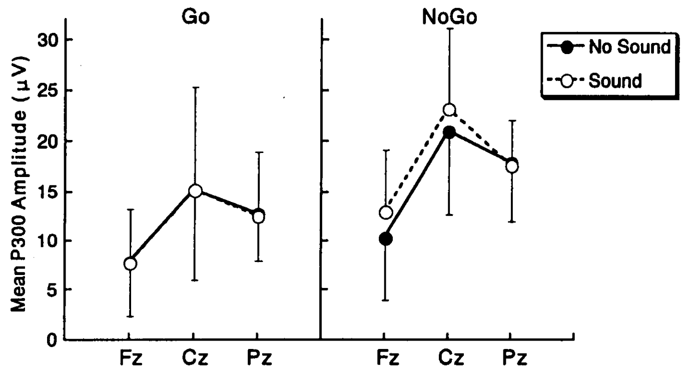

Fig. 3. Mean P300 amplitudes at Fz, Cz, Pz on Go and NoGo trials. See also the caption of Fig. 2.

$F(2,18) = 7.51$, $p < .01$.

Lateralized readiness potential: Figure 4 shows the grand averages of the LRPs for correct Go and NoGo trials. The LRP waveforms are indicated for 1100 msec from 600 msec before the IS. The vertical dashed lines indicate the onsets of the auditory accessory (A) and visual ISs (IS). Before the accessory, there is no lateralization of readiness potential for every waveforms. About 100 msec after the accessory, the initial development of the negative LRP appeared on solid waveforms. It means that the accessory brought the greater negativity about the hemispher contralateral to the response hand. The negativity between the accessory and the IS are observed on both the Go and NoGo response types. The Go and NoGo LRPs begin to differ about 100 msec after the IS. The LRPs on NoGo trials do not reach the level of the LRPs on Go trials and return to baseline sooner.

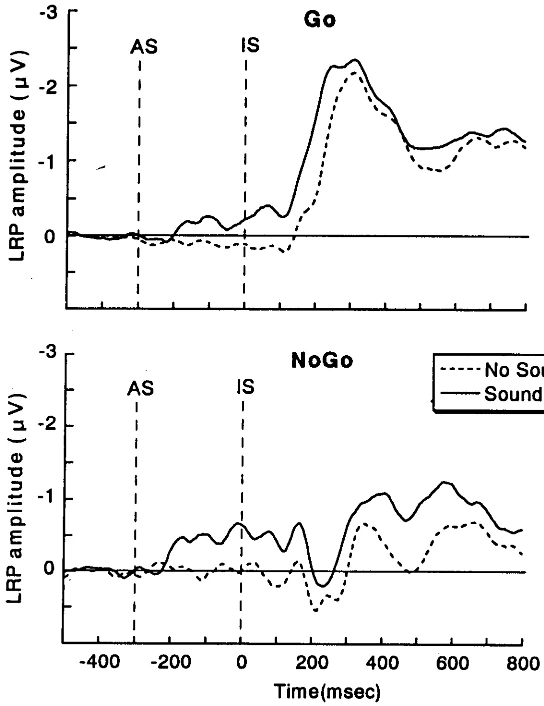

Fig. 4. Grand mean lateralized readiness potential waveforms averaged according to the response type and the accessory conditions. Upward deflections indicate greater negativity at motor related areas contralateral to the responding hand.

Discussion

The purpose of this study was to examine effects of the auditory accessory by using ERPs. These measures monitored covert processes that could not be manifested by behavioral measures. Particularly we focused on two aspects of ERPs; the P300 and the LRP. The LRP showed negative deflection about 100 msec after the accessory stimulus, and further negative going after the visual IS. This pre-IS deflection manifested that the accessory activated motor related areas at the cortex before the IS was presented. It is a psychophysiological evidence that supports the preparation enhancement model.

This result leads us to the inference that the subjects, at least partially, initiated the movement to the accessory. This possibility had been rejected by evidence that subjects made little errors on NoGo (catch) trials (Bernstein, 1970; Nickerson, 1973). Yet, recent researches exhibited that the stop signal presented just after the IS could prevent the execution of initiated movement (Meyer et al., 1988; Osman, Kornblum, & Meyer, 1986). These findings offer another explanation about the accessory effect. That is the strategical facilitation. In detail, the subjects initiated the movement process when the accessory was presented. They went on Go processing during the 300 msec interval almost near the execution. Then the IS told them whether the current processig was correct or not. At this time if the IS was the NoGo stimulus they interrupted the processing immediately and withheld the movement. Such strategies enable the aceessory to facilitate the RT to the visual IS.

This hypothesis can also explain the results that the accessory stimulus facilitates the P300 latency. Ordinary the P300 were thought to be elicited by the IS. In this paradigm, however, the accessory could elicit the P300, because it contained significant information about the movement execution for the subjects. Donchin and Coles (1988) suggested that the P300 was invoked whenever there was a need to update the expectancy about the environment. Moreover, the P300 is sensitive to unpredictable events and attentional interference. Thus, it is reasonable to believe that the initiation of the movement process by the accessory trigger such updating mechanisms. In such a way, the P300 was elicited by the accessory stimulus.

The new finding in this study was that the auditory accessory augmented the P300 amplitudes on NoGo trials. It was observed specifically at Fz and Cz. Many researchers reported that the P300 to the NoGo signal was a combination of the ordinal P300 and the NoGo-P300 (Jodo & Inoue, 1990; Pfefferbaum et al., 1983). This NoGo-P300 exhibited a more centro-frontal distribution than the Go-P300. The accessory should change the another component of the P300 occurred when the subjects inhibited a movement. The movement initiation by the accessory should produce this pschophysiological change. Once the movement process had initiated, the inhibition of the movement execution needed more efforts or energy than on non-accessory trials. The augmentation of the P300 amplitude reflected the greater activity to inhibit the movement in prefrontal areas (Sasaki, Gemba, & Tsujimoto, 1989).

In general, the accessory stimulus brought following three changes about psychophysiological measures. 1) The P300 latency was facilitated regardless of the response types. 2) The NoGo-P300 amplitude augmented at prefrontal area. 3) The LRP showed negative deflection just after the accessory presentation. From these results, we conclude that the accessory made the subjects initiated the movement process before the IS.

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