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Influence of a warning stimulus on a motor response under a backward masking paradigm.

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Abstract

In this study, we examined whether a warning stimulus affected a motor response to a visual stimulus which was not perceived with a backward masking by inferring from electromyogram reaction times (EMG-RT) and event-related potentials (ERPs). Onsets of lateralized readiness potentials (LRPs), P100 latency, and P300 amplitude, which indicate perceptual information processing and cognitive information processing, were observed. EMG-RTs and these ERPs components were affected by warning stimulus with or without the backward masking, suggesting that perceptual information processing for motor responses to the visual stimulus without awareness may be also influenced by the warning stimulus. Moreover, the degree to which a warning stimulus affected duration of perceptual information processing may not differed between under the backward masking paradigm and under other stimulus presentations. Therefore, perceptual information processing for the production of motor responses under the backward masking paradigm may be independent from much higher stages of cognitive information processing such as the attentional resources.

Key Word

reaction time, warning stimulus,
event-related potentials, information processing

1. Introduction

An onset of a motor response triggered by a visual stimulus without awareness often appears in a reaction time (RT) task within the backward masking paradigm. In the backward masking paradigm, two visual stimuli are sequentially presented with a very brief interval at a same or near visual field. The first stimulus (prime stimulus) is generally masked by the second stimulus (mask stimulus); thus, the prime stimulus is not well perceived, or, sometimes, it cannot be perceived at all. Under such perceptual conditions, responses to the pair of stimuli in the RT task occur as if the participants responded to the prime stimulus even though it may not have been consciously perceived. This results in a shortening effect on RT of masked prime stimulus.

A previous study[1] indicated that the activity of perceptual information processing evoked by the prime stimulus may contribute to the shortening of RT even when the perceptual awareness did not appear under the backward masking paradigm. Moreover, other previous studies[2] also showed that perceptual information processing for speed perceptual judgments may differ from that for the production of motor responses, suggesting that the nature of perceptual awareness as well as perceptual sensitivity of stimulus detection may not affect simple RTs in motor response. These results suggest that perceptual information processing for the production of the motor responses may be facilitated by the prime stimulus rather than by the perceptual awareness per se of the prime stimulus under the backward masking paradigm.

Nevertheless, the issue of whether the attentional resources are influential on the shortening effect of the masked prime stimulus on simple RTs under the backward masking is still far from clear. The previous studies have suggested that attentional resources, which are highly associated with perceptual awareness, often shorten choice RTs under the backward masking paradigm[3-5]. Therefore, the facilitatory effect of the masked prime stimulus may also be modulated on the simple RT task by different amounts of attentional resources under the backward masking paradigm. This was examined in this study, using a warning stimulus in the simple RT task under the backward masking paradigm. In general, a warning stimulus presented prior to the imperative stimulus in an RT task shortens resultant RTs[6, 7]. The shortening effect of a warning stimulus on RT is thought to be caused by the increase of attentional resources derived from the warning stimulus[6, 7]. If a warning stimulus facilitated perceptual information processing, this may also give rise to an effect on the activity of the motor cortex, contributing to the shortening of RTs under the backward masking paradigm.

To examine the effect of the warning stimulus on information processing for the simple RT task, we measured the neural activity of the motor cortex by measuring various event related potentials (ERPs). In the present study, we measured the lateralized readiness potentials (LRP)[8]. There are two types of LRPs: stimulus locked LRP (S-LRP) and response locked LRP (R-LRP). The S-LRP was calculated by averaging electroencephalogram (EEG) potentials in line with the onset of the stimulus on the basis of data collected from a large number of trials, while the R-LRP was calculated in line with the onset of the key-press response performed. LRPs indicate the brain activities of the contralateral motor areas specific to the hand. The latency of the S-LRP, which was defined as the time interval between the onset of the mask stimulus and the onset of the S-LRP, indicate duration needed for perceptual information processing in the simple RT tasks. The latency of the R-LRP indicates duration of motor information processing in the simple RT task.

Moreover, we measured P100 and P300 components in this study. The ERP components appearing within 200 ms after the onset of the mask stimulus have generally been thought to be associated with the early stages of perceptual information processing. For relatively late ERP components, P300 was used in this study. The P300 component is generally thought to indicate the neural activity associated with cognitive aspects on the given stimuli, such as participants' awareness of the given stimuli, expectancy for the presentation of stimuli, and the state of updating the stimulus context[9]. In this study, both the participants' expectancy for the presentation of stimuli and updating the stimulus context were manipulated to be invariable by randomly setting the duration of the foreperiod used in the RT task and counterbalancing the sequential order of visual stimulus presentation among the stimulus conditions. Therefore, these manipulations should result in the participants' awareness of stimuli alone to be largely reflected on amplitude of P300.

2. Methods

2.1. Participants

Six males and three females, all right-handed with a normal or corrected vision, participated in this experiment. Informed consent was obtained from each participant.

2.2. Apparatus and Stimuli

In this study, a Visual-Stimulus-Generation System (VSG2/5, Cambridge Research Systems) was used with a 19-inch CRT monitor with vertical refresh rate of 170 Hz (GPD-G420, Sony) at a viewing distance of 80 cm. Participants sat on a chair in front of the VSG2/5 system and rested their head on a chin support. For the stimuli, the mask stimulus was a graphical square (1.2°× 1.2°) with the exposure duration of 100 ms, while the prime stimulus was a graphical circle of 0.8° in diameter with the exposure duration of 12 ms. The luminance of the mask stimulus was 7.1 cd/m^2 and that of each random-dot of the background stimuli was 3.6 cd/m^2, respectively. For the prime stimulus, the luminance was manipulated for each participant so as to determine the probability of correct detection of the prime stimulus at either 50% or 80% in a two-alternative forced choice (2-AFC) task (see the details at the procedures section).

The isometric force and RT of responses to a visual stimulus were measured with a U-shaped steel plate (30×3.7×0.3 cm) placed on a solid base, which the participants squeezed by the thumb and the other four fingers. The isometric force of squeeze was transformed into analog output in voltage, via strain gauge attached on a curve of the U-shaped plate, and then amplified with an amplifier (DPM-700B, KYOWA). The analog outputs of squeeze force were converted at a rate of 1 kHz into digital data and then stored in the memory device on a Macintosh 8500/150 (Apple computer) via an acquisition unit (PowerLab/16s, AD Instruments).

2.3. Procedures

This experiment consisted of two sessions. The first was a 2-AFC task, which was conducted to estimate the threshold levels for the 50 % and 80 % of correct detection of the masked prime stimulus for each participant. The 2-AFC task started with a beep tone (59 ms duration) and, 588 ms after, either the mask stimulus-only or the set of the prime plus mask stimuli (with a 35 ms stimulus onset asynchrony (SOA) between the prime and mask stimulus) was presented and, in turn, the other visual stimulus set was presented. The presentation order of these two sets of stimuli was random among trials. The interval between the two sets of visual stimulus was 1176 ms. Participants were then asked to answer, by pressing an appropriate key, whether the set of the prime plus mask stimuli was presented first or second in the sequential presentations of the two stimulus sets.

The luminance of the prime stimulus was manipulated so as to determine the probability of correct discrimination between the prime plus mask stimuli condition and the mask stimulus-only condition to be at either 50% or 80% in the 2-AFC task, using the weighted up-down procedure[10]. In this procedure, when the participant correctly discriminated the two visual stimulus conditions, the luminance of the prime stimulus was weakened by a step of 0.34 cd/m^2 for both the 50% and 80% correct discrimination conditions, while after each incorrect discrimination the luminance of the prime stimulus was increased by a step of either 0.34 cd/m^2 for the 50 % or 1.36 cd/m^2 for the 80 % correct discrimination condition. The starting luminance of the prime stimulus in the 2-AFC task was 7.1 cd/m^2. Each step width was held constant through all the trials. The 2-AFC task was terminated when the up-down luminance changes in the prime stimulus was switched 18 times in the procedure. Discarding the first two luminance values, the remaining 16 luminance values were averaged for the 50 % and 80 % correct discrimination conditions, respectively. The mean luminance value obtained through such procedures was dealt with as the threshold luminance of the prime stimulus for each condition.

The second session was a simple RT task, in which a warning tone was either presented or not presented prior to either the prime or mask stimulus in each trial. This was used to manipulate whether the alert for the up-coming stimulus was presented or not at each block of trials.

For the procedures specific to the simple RT task, participants were asked to gaze a fixation point during each trial and to respond to given visual stimuli as fast as possible by squeezing with either the right or left hand in an arbitrary force of muscular contraction the U-shaped steel device. The order of the use of the right and left hands was manipulated in counterbalanced order among participants. Each trial commenced with the presentation of both a background stimulus (which was varied for trials) and a fixation point. One second after the commencement of each trial, a beep tone (58.8 ms in duration) as a warning stimulus was presented in the warning condition, while in the non-warning condition any warning stimulus did not appear. Either the warning or non-warning condition was set in each block of trials. The foreperiod between the warning stimulus and the imperative stimulus (i.e., either a prime or a mask stimulus) was presented randomly. The length of foreperiod was determined so as to be in an exponential distribution, resulting in longer than 882.3 ms[11]. The three visual stimulus conditions were used: the mask stimulus-only condition, and the 50% and the 80% threshold conditions. At the 50% and the 80% threshold conditions, both the prime and mask stimuli were presented with the 35.2 ms SOA. One of the three visual stimulus conditions was randomly presented at each trial. The background stimuli disappeared at the end of each trial (1 s after the offset of the mask stimulus). Intertrial intervals ranged from 3 to 7 s. For RTs either shorter than 100 ms or longer than 500 ms, a beep tone was given after the trial to encourage the participant to attend to stimuli presented. A short rest was given between the experimental blocks of trials. Trials in the simple RT task were performed 24 blocks of 25 trials, for a total of 600 trials, consisting of 100 trials per stimulus condition and alerting condition (i.e., warning or non-warning conditions).

2.4. EEG, EOG, and EMG recording

Electroencephalogram (EEG), electrooculogram (EOG), and electromyogram (EMG) were measured in the simple reaction time task with NeuroScan system. EEGs were derived with the tin electrodes in QuickCap from Fz, Cz, Pz, Oz, C3, C4 with linked reference as a mastoide connection. These signals were amplified by high-cut frequency of 50 Hz. Vertical EOG was measured from the left eye with 2 Ag/Cl electrodes in a bipolar fashion and the recording setting was low-cut frequency of 0.1 Hz, high-cut filter of 100 Hz. EMG was measured from the ventral forearm on the palmaris longus muscle (band pass: 5-200 Hz). All electrophysiological signals were digitized at 1000 Hz, and electrode impedances were kept below 5 kΩ on the scalp and the face and below 20 kΩ on the arms during experiment.

2.5. Data analysis

Trials with either EEG data contaminated by artifacts, such as eye movements, blinks, and motion artifacts, or RTs either shorter than 100 ms or longer than 1000 ms were discarded in subsequent analyses. ERPs were computed per visual stimulus condition and warning condition for each participant. The baseline amplitude for S-LRP, P100, and P300 was calculated as the mean amplitude for the preceding period of 200 ms prior to the onset of the mask stimulus. For the R-LRP, the baseline period was set at the range from 500 ms to 350 ms prior to the key-press performed in each trial.

LRPs (for both the S-LRP and R-LRP) were calculated on the basis of EEG signals collected at both the C3 and C4 for both the right and left hands, using the double subtraction method[8]. The onset of either the S-LRPs or R-LRPs was defined as the time at which the amplitude/potential of the LRP waveform exceeded higher than 50% of the peak amplitude of the LRP waveform for at least 100 ms successively. The latency of the S-LRP was defined as the time interval between the onset of the mask stimulus and the onset of the S-LRP, while the latency of the R-LRP was defined as the elapsing time from the onset of the R-LRP until the key press. The latencies of both the S-LRPs and R-LRPs were calculated for each participant and each visual stimulus condition.

The peak amplitudes of ERPs were determined as the largest positive amplitude appearing in a range from 250 to 600 ms for P300. The amplitudes of P300 were calculated as the difference between the baseline and the peak amplitude. The latencies of P100 were defined as the time elapsing from the onset of the mask stimulus to the respective peak amplitudes of P100.

The peak force was defined as the difference between the peak force and the baseline force which was the mean force during the time range of 200 ms prior to the onset of the mask stimulus. The EMG-RT was defined as the time interval elapsing from the onset of the mask stimulus to the onset of EMG activity and the motor time was defined as the time elapsing from the onset of EMG to the initial change in force production performed on the U-shaped device. The onset of the change in force production was defined as the time when the force increased by 5% of the peak force. The means of EMG-RT, motor time, and the peak force were calculated per condition for each participant. Two-way analysis of variance (ANOVA) on EMG-RT, motor time, and peak force were separately conducted, with repeated-measures on both stimulus condition and alert condition. The significance level of ANOVAs was adjusted according to the procedure of Greenhouse and Geisser correction. The Tukey HSD procedure was used for post hoc, multiple comparisons tests for significant main effects.

3. Results

3.1. Behavioral data

The mean EMG-RT, motor time, and peak force for each condition are illustrated in Figure 1. The mean EMG-RT was the shortest at the 80% threshold condition, then prolonged for the 50% threshold condition, and was the longest at the mask stimulus-only condition. This was the same for both the warning and non-warning conditions. A two-way ANOVA showed a significant main effect for stimulus condition (F (2, 16) = 76.84, MSe = 30.85, $p < .001$) and for alert (F (1, 8) = 9.51, MSe = 403.62, $p < .05$), with no significant interaction between the two factors (F (2, 16) = 0.42, MSe = 28.55). Post hoc analyses were then conducted with the Tukey HSD tests, resulting in that the means of EMG-RT significantly differed for the three stimulus conditions as well as for the warning and non-warning conditions ($p < .05$).

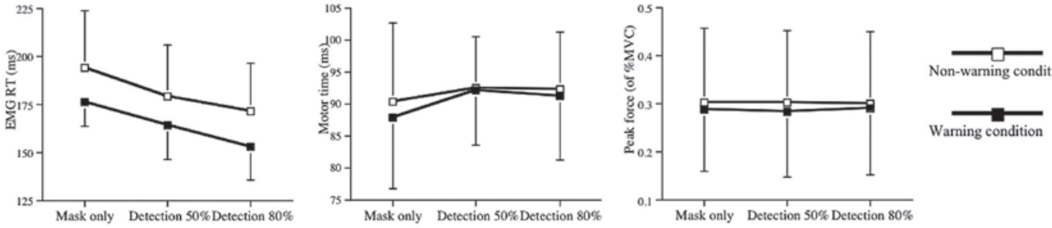

Figure 1. EMG RT, motor time, and Peak force for each condition.
Note: The vertical bars indicate standard deviations.

The mean motor time did not significantly differ either among the three stimulus conditions or between the two alert conditions. The two way ANOVA showed a significant effect for neither stimulus condition (F (2, 16) = 2.24, MSe = 30.65, $p > .1$) nor alert condition (F (1, 8) = 0.31, MSe = 26.60), with no significant interaction between the two factors (F (2, 16) = 2.85, MSe = 2.19, $p > .1$). These results indicated that the time needed for the whole processes for the production of muscular contraction did not differ for either experimental conditions irrespective of stimulus and alert conditions under the backward masking paradigm.

The mean peak force at the non-warning condition was slightly significantly larger than that of the warning condition (F (1, 8) = 5.96, MSe = 0.001, $p < .05$), with neither significant difference between the left and right hands (F (2, 16) = 0.37, MSe = 0.00008) nor significant interaction between the two factors (F (2, 16) = 1.16, MSe = 0.001, $p > .1$). These results suggested that the production of force was slightly larger for the presentation of a warning stimulus than that for no warning, with no significant difference for the three stimulus conditions.

3.2. Lateralized readiness potentials

Grand averages of S- and R- LRP waveforms are illustrated in Figure 2. The onset of S-LRP at the warning condition appeared earlier than that of non-warning condition. The latency of S-LRP occurred the earliest for the 80 % threshold condition and then prolonged for the 50% threshold condition, with the latest for the mask stimulus-only condition. An ANOVA showed a significant main effect for both alert condition (F (1,8) = 11.7, MSe =92.36 , $p < .01$) and stimulus condition

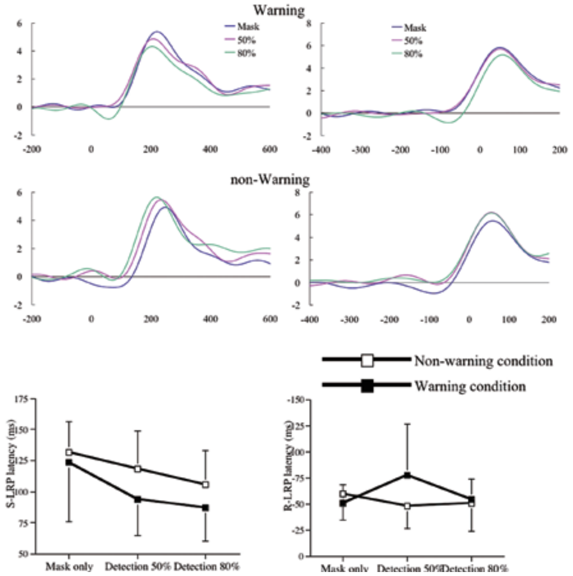

Figure 2. Grand averaged S- and R-LRP waveforms & latencies at left and right panels, respectively.
Note: In upper panel, the S- and R- LRP waveform. In lower panels, the latencies of S- and R-LRP. The vertical bars indicate standard deviations.

(*F* (2, 16) = 6.71, *MSe* = 700.13, *p* < .05). The Tukey HSD tests for stimulus condition showed that the latencies of S-LRP for both the 50% and 80% threshold conditions appeared significantly earlier than that for the mask stimulus-only condition, with no significant difference for the 50% and 80% threshold conditions. The ANOVA also showed no significant interaction between the two factors (*F* (2, 16) = 0.03, *MSe* = 1192.43), indicating that the shortening effect of a warning stimulus on the latency of S-LRP was equivalent among the three stimulus condition.

The onset of R-LRP appeared in a range of 40 to 100 ms before the onset of EMG activity. An ANOVA showed a significant main effect for neither alert (*F* (1, 8) = 0.68, *MSe* = 1401.25) nor stimulus conditions (*F* (2, 16) = 1.177, *MSe* = 458.08), with no significant interaction (*F* (2, 16) = 1.15, *MSe* = 838.6). These results indicated that the time for motor information processing at the motor cortical areas for the production of motor responses differed for neither stimulus condition nor warning condition.

3.3. P100 latency

Grand averaged ERP waveforms are illustrated in Figure 3. A positive deflection of P100 clearly appeared in a range of 80 to 150 ms at Pz and Oz electrode positions. The latency of P100 was the shortest for the 80% threshold and then prolonged for the 50% threshold, with the latest for the mask stimulus-only condition (Figure 4.). An ANOVA on the latencies of P100 showed a significant main effect only for stimulus condition (*F* (2, 16) = 8.58, *MSe* = 303.68, p < .01) but for neither alert (*F* (1, 8) = 0.211, *MSe* = 420) nor electrode (Oz and Pz alone) position (*F* (1, 8) = 0.32, *MSe* = 485.52). For interactions, the ANOVA showed a marginally significant interaction between stimulus condition and electrode position (*F* (2, 16) = 3.98, *MSe* = 180.81, *p* < .1) but showed significant interaction neither between alert and stimulus condition (*F* (2, 16) = 1.77, *MSe* = 218.22), between alert and electrode position (*F* (1, 8) = 0.23, *MSe* = 413.12), nor the three-way interaction (*F* (2, 16) = .011, *MSe* = 186.83). The marginally significant interaction between stimulus condition and electrode position indicated that the effect of stimulus condition on P100 latency slightly differed between Pz and Oz electrode positions. For this interaction, subsequent simple main effect tests were performed and showed significant simple main effects for stimulus condition at both the Oz (*F* (2, 32) = 3.01, *MSe* = 242.24, *p* < .05) and Pz (*F* (2, 32) = 10.71, *MSe* = 242.24, *p* < .05) electrode positions. At the Oz electrode position, the latency of P100 at 80% threshold condition was shorter than that of all the other conditions, with no significant difference between the 50% threshold condition and the mask stimulus-only condition. In contrast, at the Pz electrode position, the latencies of P100 at both the 80% and 50% threshold conditions were shorter than that of the mask stimulus-only condition.

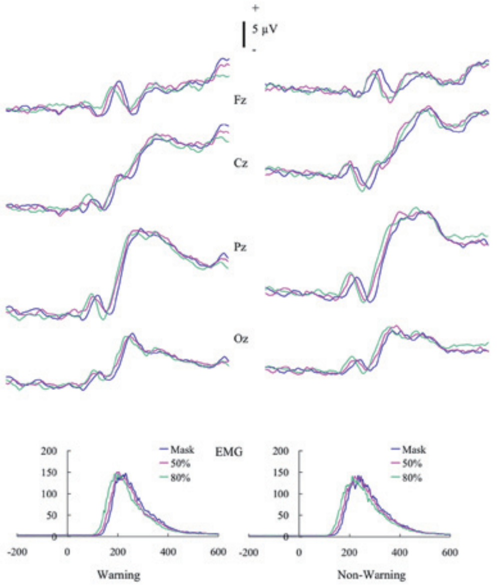

Figure 3. Grand ERP waveform at each condition.

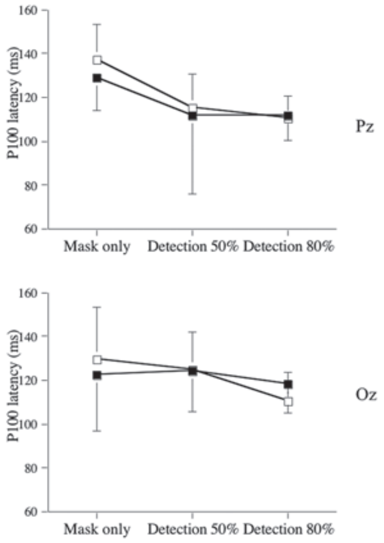

Figure 4. The mean P100 latencies at Pz and Oz

3.4. P300 amplitude

The mean amplitudes of P300 are illustrated in Figure 5. Large P300 amplitudes appeared in the Pz electrode location. An ANOVA showed a marginal significant main effect for alert (*F* (1, 8) = 3.54, *MSe* = 10.13, *p* < .1), a significant main effect for electrode position (*F* (3, 24) = 16.3, *MSe* = 45.39, *p* < .001) but did not show any significant main effect for stimulus condition (*F* (2, 16) = 0.2, *MSe*= 4.97). For interactions, the ANOVA showed a significant interaction between alert and electrode position (*F* (3, 24) = 3.51, *MSe* = 3.72, *p* < .05) but did not show any other significant interactions (*F* (2, 16) = 0.75, *MSe* = 3.54, between alerting and stimulus conditions interaction; *F* (6, 48) = 0.28, *MSe* = 5.79, between stimulus and electrode conditions interaction; nor *F* (6, 48) = 0.94, *MSe* = 1.48, for the three-way interaction). For the significant interaction between alert and electrode position, simple main effect tests were subsequently performed. The simple main effect for alert was significant at Cz (F(1, 32) = 9.96, *p* < .001) alone but not at the other sites (Oz: *F* (1, 32) = 0.18; Pz: *F* (1, 32) = 0.092; Fz: *F* (1, 32) = 3.90, *MSe* = 4.17).

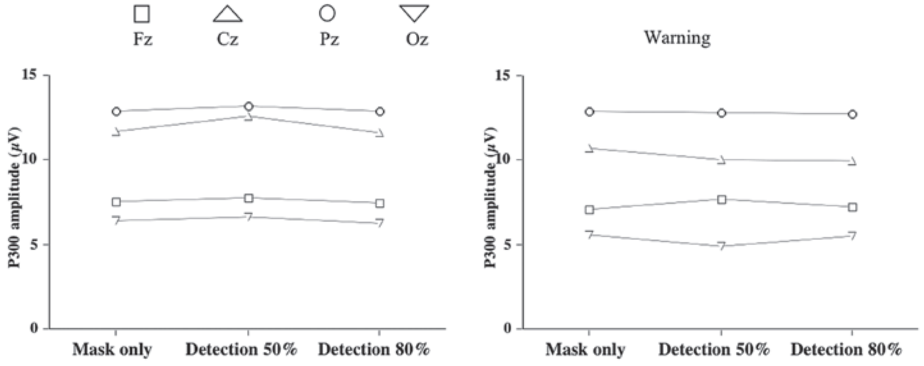

Figure 5. Mean P300 amplitude

4. Discussion

The results in this study showed that the interaction between alert (i.e., the warning and non-warning conditions) and stimulus condition (i.e., mask stimulus-only condition, the 50 %, and the 80 % threshold conditions) was not significant on neither dependent variable, such as neither EMG RT, peak force, S-LRP, R-LRP, P100 latency, nor P300 amplitude. The presentation of a warning stimulus in this study showed only a usual facilitation effect on motor responses (EMG-RT) as well as on perceptual processes (as indicated in the latencies of S-LRP and P100). These results indicated that the increase of attentional resources given by the presentation of a warning stimulus did not modulate any facilitatory effects of the masked prime stimulus on the shortening of RTs under the backward masking paradigm. These suggests that the increment of attentional resources would not affect the mechanisms of perceptual and/or motor information processing which is facilitated by the masked, unseen prime stimulus under the backward masking. In other words, the facilitatory effect of the masked prime stimulus on motor responses under the backward masking may probably be mediated by likely facilitatory effects on motor stages, rather than perceptual/attentional stages, of information processing.

This study showed that the peak force for the non-warning condition was larger than that for the warning condition. The increase of attentional resources induced by the warning stimulus may have forced the participant to well prepare the necessary conditions for the production of a motor response to an imperative stimulus (i.e., either the prime or mask stimulus) in the simple RT task under the backward masking paradigm. Such an effective preparation for motor responses to the imperative stimulus may have facilitated responses with shorter RTs than under the non-warning condition without the warning stimulus and with less force, namely, performing energy-efficient motor responses. In other words, the increase of attentional resources may decrease the energy of responses, resulting in a small force production.

In this study, the amplitude of P300 was increased by the warning stimulus at the Cz electrode position alone but was not affected at either Pz or Oz, both of which are located much closer to the visual, perceptual cortical areas. The electrode cite of Cz should primarily reflect cortical activities around both the motor and somatosensory cortical areas. Therefore, the result of the increased amplitude of P300 appearing at Cz alone, rather than Pz and Oz, in this study may well be explained in terms that the increment of attentional resources should induce a facilitaory influence on both the motor and somatosensory information processing. Although it has been suggested that a warning stimulus increases attentional resources and this should in turn facilitate either perceptual, attentional, or cognitive information processing, some previous studies have also suggested that the effects of a warning stimulus largely appear in the motor stages of information processing in RT tasks[6, 12, 13]. Furthermore, it is suggested that P300 component reflects the nature of motor information processing for the production of motor responses in an RT task[14]. Therefore, the presentation of a warning stimulus may activate the motor cortex, so that the amplitude of P300 at Cz may have become to be larger with a warning stimulus than that with no warning stimulus.

5. Conclusions

Although the increment of attentional resources induced by a warning stimulus affected the RT, P100, S-LRP, and P300, the interaction between stimulus condition (i.e., the mask stimulus-only, 50% threshold, and 80% threshold conditions) and warning condition (i.e., with or without the warning stimulus) was not significant on either of these dependent variables. This suggested that the attentional resources did not modulate the facilitatory effect of the masked prime stimulus on the shortening effect of RTs under the backward masking paradigm. Rather, the effect of the masked prime stimulus (perceived without awareness) on the shortening of RTs may be mediated by a likely facilitation, or triggering, of the motor stages of information processing. Therefore, the stages of perceptual information processing related to the production of motor responses under the backward masking paradigm may be activated in different pathways, which should be independent from much higher stages of cognitive information processing, such as the attentional resources.

6. References

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