P3 Latency is Related to Temporal Lag between Two Targets during the Attentional Blink

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Abstract: When two target stimuli (T1 and T2) are embedded in a rapid serial visual presentation (RSVP) stream of distractors and presented at variable stimulus onset asynchronies (SOAs), detection of T2 is impaired at SOAs of less than 600 ms. This phenomenon is called attentional blink. However, the attentional blink is often observed only if T2 is masked by a trailing stimulus. In the present study, T2 was the last item in the stream, and therefore unmasked. As a result, the typical attentional blink was not observed and the amplitude of the P3 component of the event-related potential (ERP) time-locked to T2 onset did not decrease. However, P3 latency was delayed with respect to the length of SOA between T1 and T2. Many studies have reported that the decrease in accuracy of detecting T2 in the attentional blink paradigm recovers as SOA of targets increases. Our results suggest that the brain process reflected in the P3 component is closely related to the strength of the attentional blink deficit.

Keywords: Attentional blink, P3 latency, ERP, Masking

1. Introduction

Rapid serial visual presentation (RSVP) is often used to study difficulty in shifting attention. RSVP is a rapid stream of visual stimuli in which some targets are embedded. When there is one target in this stream, the targets are correctly reported in almost all trials. When there are two targets in the stream, the first target (T1) is reported correctly; however, observers often miss the second target (T2) when there is a time lag of a few hundred milliseconds between T1 and T2 (Broadbent & Broadbent, 1987 [1]). This decrease in the accuracy of detecting T2 is called the attentional blink phenomenon. Accuracy is recovered as the stimulus onset asynchrony (SOA) of the targets increases (Raymond, Shapiro, & Arnell, 1992 [2]).

In the present study, we used event-related potentials (ERPs) derived from an electroencephalogram (EEG) to measure the time course of target processing. We focused on the P3 wave, which is the third major positive ERP component and typically peaks about 300–600 ms after a visual target is presented. P3 latency and amplitude reflect postperceptual and cognitive processes (e.g., Picton, 1992 [3]; Kok, 2001 [4]).

Vogel, Luck, & Shapiro (1998) [5] showed that the amplitude of the P3 component time-locked to T2 onset was reduced at short intervals between targets. They concluded that the attentional blink reflected impairment in a postperceptual stage of cognitive processing. Recently, studies have focused on the relationship between T1–T2 time lags and the latency of the P3 component time-locked to T2 onset.

Giesbrecht & Di Lollo (1998) [6] showed that attentional blink is found only when T2 is masked by a trailing stimulus; therefore, T2 is the final item in the RSVP stream. This research indicated that backward masking played a key role in the attentional blink. In this paradigm (T2 is not masked), the amplitude of the P3 component is never attenuated; thus, this paradigm facilitates
the examination of P3 latency. Some researchers using this paradigm failed to observe the attentional blink; however, other studies have reported that the P3 wave was delayed but not suppressed under these conditions. (Vogel & Luck, 2002 [7]; Sessa, Luria, Verleger, & Dell’Acqua, 2007 [8]).

However, these studies [7] [8] only compared P3 latency at target intervals when the occurrence of the attentional blink was the highest (about 250 ms) and when the attentional blink was not observed (more than 700 ms). Therefore, we supposed that these studies were unable to demonstrate a close relationship between changes in response accuracy and P3 latency as a function of the interval between targets. We examined this in more detail by using a wider range of T1–T2 time lags to study the relationship between T1–T2 time lags and P3 latency and the beginning of the occurrence of the attentional blink.

2. Method

Participants
A total of 14 university students and researchers (6 men and 8 women, 20–35 years old, average age: 23.80 years) participated in the experiment. Participants reported that they had normal or corrected-to-normal visual acuity, normal color vision, and no history of neurological problems.

Stimuli and procedure
Stimuli were presented on a computer monitor with a gray background (10.5 cd/m²) at a distance of about 70 cm. As shown in Figure 1, each trial consisted of a rapid serial stream of 19 digits and a single letter. Each character in the stream was presented individually for a fixed time of 50 ms, followed by a 33 ms inter stimulus interval. The characters were 1.0° in height and varied proportionally in width. Non-targets were randomly selected digits written in black (3.5 cd/m²). T1 was a digit written in white (31.1 cd/m²) and T2 was a capital letter (A, S, D, F, G, or H) written in black; this letter appeared in 25% of the trials and other digits selected at random appeared in 75% of the trials. At the end of each trial, the participants pressed the corresponding numbers in the correct order and typed the corresponding letter keys on the computer keyboard or the spacebar if T2 was not detected. There was no time limit for these responses. T2 was the first, third, fifth, or seventh item following T1 (denoted as lag 1, 3, 5, or 7, respectively). In addition, it was either the last item in the stream (unmasked) or was followed by two distractors (masked). Because each sequence consisted of 20 stimuli, the sequential position of T1 was determined by the T1–T2 lag and by whether T2 was the final item in the sequence or third from the end. Participants performed 256 trials for each combination of the lag and the masked condition distributed across eight blocks.

Fig. 1: Example of the RSVP paradigm used in this experiment. T1 was a white digit. T2 was a black letter and presented as the first, third, fifth, or seventh item following T1. In this figure, T2 is followed by a masking letter (the masked condition). Under a different condition, T2 was the last item of the sequence (the unmasked condition).

Recording and Analysis
EEG measurements were conducted with an EEG recording system (Neuroscan) by using an Easy Cap (Falk Minow Service) with 32 Ag/AgCl electrodes (30 EEG electrode sites [Fp1, Fp2, Fz, F3, F4, F7, F8, FCz, FC3, FC4, FT7, FT8, Cz, C3, C4, T7, T8, CPz, CP3, CP4, TP7, TP8, Pz, P3, P4, P7, P8, Oz, O1, and O2] and vertical and horizontal electrooculogram [EOG] electrodes. In this study, EEG was recorded only in the unmasked condition because an attenuated P3 component under the masked condition was unsuitable for examining its latency, as described below. Data were digitized at 500 Hz and filtered online using 0.1–100 Hz band-pass filters. The nose tip was used as reference. To minimize distortion of the phase, a notch filter was not used.

EEG was digitally low-pass filtered off-line at 30 Hz (6 dB/octave) with a finite impulse response filter. Trials that included ocular artifacts (primarily eye blinks) were excluded from the averaged ERP waveforms. These arti-
facts led to the rejection of a mean of 5% of the trials (the maximum rejection rate for an individual participant was 12%). The averaged ERP waveforms were time-locked to the onset of the T2 letter. Moreover, trials with incorrect T1 responses were excluded from the ERP waveforms and all behavioral analyses. The onset latency of the P3 component was measured using its fractional area latency, which was defined as the time point at which the waveform reached 25% of its area within a 300–900 ms post-stimulus time window (Hansen & Hillyard [9], 1984; Vogel & Luck, 2002 [7]; similar results were obtained with conventional peak latency measures). P3 amplitude was measured as the mean amplitude of the waveform from 300 to 900 ms. All analyses were restricted to the central and parietal electrode sites, where the P3 wave was the largest, but the same pattern was observed across the scalp. The data from two midline electrode sites (Cz and Pz) were analyzed statistically.

All analyses of variance (ANOVAs) for behavioral and electrophysiological results used the Huynh–Feldt ε correction to evaluate F ratios for repeated measures involving more than one degree of freedom.

3. Results

Behavioral Performance

Under the masked condition, T2 accuracy increased as the lag between T1 and T2 increased (Figure 2). One-factor ANOVA performed with the Lag (Lag 1, 3, 5, or 7) as a repeated measures factor revealed a significant main effect of the Lag, $F(3,39) = 26.29$, $p < .01$, $\epsilon = .42$. It was shown that accuracy improved in the order: Lag 1, 3, 5, and 7 ($p < .05$).

Under the unmasked condition, T2 accuracy was at a considerably high level at all Lags except at Lag 1 (Figure 3). One-factor ANOVA (4 Lags) of T2 accuracy and the Bonferroni multiple comparison test revealed the significant main effect of the Lag, $F(3,39) = 14.07$, $p < .01$, $\epsilon = .66$, and that the accuracy at the shortest lag condition (Lag 1) was significantly lower than that at the other three lags.

These results suggest that the typical attentional blink was observed under the masked conditions. However, under the unmasked condition, accuracy was lowest at the shortest lag (Lag 1). It is believed that the difference between the present results and previous studies is attributable to the strength of forward masking, which is likely to have served as a more effective masking because the brightness of non-target stimuli was higher than that used in previous studies.

ERP

The data of 12 participants were adopted for ERP analyses; the data of the other two participants were excluded because of various artifacts that existed in their trials. The difference wave was calculated at Cz and Pz under the unmasked condition by subtracting trials in which two targets (digit and letter) were presented from those in which only one target (digit) was presented (Figure 4. In Figure 4, the positive component peaking around 500 ms can be considered to be the P3 component.
P3 at Lag 1 was suppressed along with a decrease in T2 accuracy. At Lags 3, 5, and 7, P3 latency was delayed; however, P3 amplitude was not reduced. Delay decreased as a function of the length of the T1–T2 lag.

Figure 5 shows the mean P3 latency at Pz. From this figure, it can be concluded that P3 latency at Lag 3 was delayed by about 80 ms compared with that at Lag 7. Two-factor (2 Electrodes × 4 Lags) ANOVA showed significant main effect of only Lag, $F(3, 33) = 5.86, p = .007$. In addition, P3 latency was longest at Lag 3 and shortest at Lag 7.

Two-factor (2 Electrodes × 4 Lags) ANOVA of P3 amplitude and the Bonferroni multiple comparison test showed significant main effects of only Lag, $F(3,33) = 6.43, p = .02, \eta^2 = .94$, and that the P3 amplitude was significantly lower at Lag 1 compared to those at other

4. Discussion

Under the masked condition, the typical attentional blink was observed; however, the same was not observed under the unmasked condition. The difference between the two conditions is whether a masking stimulus after T2 was observed. This shows that it is important that T2 is masked by a following stimulus for the occurrence of the attentional blink.

The latency of the P3 component was highly delayed at Lag 3 compared with that at Lag 7. These results are in accordance with a previous study. Furthermore, P3 latency at Lag 5 was midway between those at Lags 3 and 7. Our results suggest that the brain process reflected in the P3 component was closely related to the strength of the attentional blink deficit.

Previous research has shown that the P3 component strongly reflects the updating of working memory and that P3 latency is related to cognitive processing time (Donchin & Coles, 1988 [10]). The results of this study agree with the “two-stage model” (Chun & Potter, 1995 [11]) which explains that the attentional blink phenomenon is a result of a second-stage bottleneck with respect to the target.

Recently, an explanation of the attentional blink has been proposed that does not assume the delay of processing (e.g., Nieuwenstein, 2006 [12]). Another study (Kihara, Kawahara, & Takeda, 2008 [13]) that used RSVP with the continuous presentation of multiple targets reported that, when all targets were correctly identified, there was no influence of the Lag on the P3 component. However, in our study, the differences in P3 latency with respect to the time lag between T1 and T2 corre-
responded to the accuracy with which T2 was identified. Therefore, it is believed that when T2 is followed by a masking stimulus, the attentional blink is caused by cognitive processing related to target identification during the delay.

There are still many unsolved problems concerning the occurrence of the attentional blink. The problem of temporal attention phenomena such as the attentional blink pertains to changes over a significantly short time. Therefore, electrophysiological methods may be considerably useful to resolve this problem.

References


