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A Failure in Goal Achievement Interrupts Ongoing Task Execution

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Abstract

When interacting with a computer, we select an action due to our expectation of its effect. However, we sometimes receive a computer response that differs from our expectation. In this study, we recorded event-related brain potentials (ERPs) during a cursor movement task. Twenty-two university students were asked to move a cursor over a goal line by pressing one of two buttons: the left-lower button, which moved the cursor to the left-lower position; and the right-upper button, which moved the cursor to the right-upper position. First, the cursor appeared at the center of the screen. A goal line then appeared in one of the four positions: upper, lower, right, or left. Participants were asked to press the buttons to move the cursor across the goal line. In most trials (p = .75), the cursor crossed the line (i.e., the goal was achieved) after the button was pressed twice. In the other trials, the cursor moved irregularly (p = .25). In half of the deviant trials, the cursor still crossed the line (i.e., the goal was inadvertently achieved). In the other deviant trials, the cursor moved but did not cross the line (i.e., the goal was missed). Participants also undertook a secondary task, where they were asked to press a button in response to a probe stimulus that was presented infrequently at the center of the screen after the second button press in the main task. Results found that behavioral responses to probe stimuli were delayed when the goal was not achieved, compared to when the goal was achieved either predictably or inadvertently. When the goal was missed, a large negative wave (N2) of the ERP occurred at a latency range of 200 to 250 ms. This result suggests that a failure in goal achievement—and not the occurrence of an infrequent event—causes behavioral distraction.

Key words: *Action effects, Expectation, Behavioral delay, Failure in goal achievement*

Introduction

When we interact with a computer or an appliance, we select and execute an appropriate action in order to achieve a certain goal. During this operation, we have certain expectations about the effect of our action. However, an action sometimes produces an event that is different from our expectation. The action effect can deviate from our expectation in two ways: First, the sensory consequences of an action are different from the expected ones. Second, such a deviation indicates a failure in goal achievement. To put it differently, unexpected action effects can be regarded as a failure or as an unusual but acceptable outcome.

Many studies have demonstrated that deviant events interrupt ongoing task execution (Jankowiak & Berti, 2007). When a deviant event occurs, our attention is involuntarily captured by it and a behavioral delay occurs in the main task (Notebaert, Houtman, Van Opstal, Gevers, Fias, & Verguts, 2009). It remains unclear, however, whether a failure in goal achievement affects this behavioral delay.

The present study addresses the cause of the behavioral delay after an unexpected action effect. To investigate cognitive processes underlying the behavioral delay, we recorded event-related brain potentials (ERPs). ERPs have been proposed as a tool of assessing the state of attention in human–computer interactions (Nittono, 2005). A previous ERP study showed that the effects of unexpected actions elicited mismatch-related ERP components, such as N2 and P3, and delayed the next response (Iwanaga & Nittono, in press). The N2 is assumed to reflect a self-monitoring process after the execution of an action (Katahira, Abla, Masuda, & Okanoya, 2008), and is possibly elicited when the action produces a worse-than-expected outcome (feedback-related negativity; Holroyd & Coles, 2002). The P3 reflects an attention orienting process in response to deviant events (Sawaki & Katayama, 2007). In the present study, we compared ERPs elicited by the two types of unexpected action effects to examine the cognitive processes underlying behavioral delays.

Methods

Participants

Twenty-two university students (9 men and 13 women) participated in the study (19–24 years old, M = 21.2 years old). Eighteen participants were right-handed, one participant was left-handed, and three participants were ambidextrous. All of them had normal or corrected-to-normal vision. They gave written informed consent.

Stimuli and Procedure

Cursor movement task (Figure 1A). Participants were asked to press one of the two buttons: the left-lower button, which moved the cursor (asterisk) to the left-lower position, or the right-upper button, which moved the cursor to the right-upper position. First, the

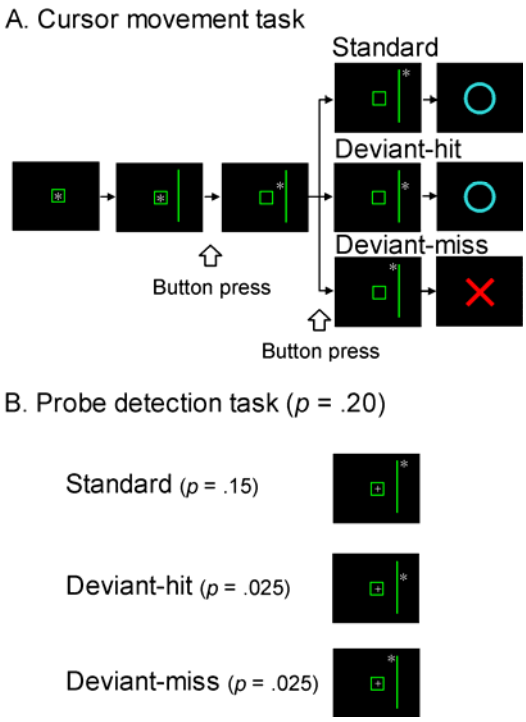

Figure 1. A: Illustration of the sequence of events in each trial. B: Participants were also asked to press a button in response to a probe stimulus infrequently presented.

cursor appeared at the center of the screen. Then, a goal line appeared in one of the four positions: upper, lower, right, or left. Participants were asked to press the buttons to move the cursor across the goal line. In most trials (p = .75), the cursor crossed the line after the button was pressed twice (i.e., the goal was achieved; *standard* trials). In the other trials, the cursor moved irregularly (p = .25). In half of the deviant trials, the cursor still crossed the line (i.e., the goal was inadvertently achieved; *deviant-hit* trials). In the other deviant trials, the cursor moved, but did not cross the line (i.e., the goal was missed; *deviant-miss* trials). As a correct feedback, a blue circle was presented when participants achieved the goal (i.e., in the standard and deviant-hit trials). When participants did not achieve the goal, a red X was presented as an error feedback. Six blocks with 80 trials each were conducted.

Probe detection task (Figure 1B). Participants also undertook a secondary task. They were asked to press a button in response to a probe stimulus (plus sign) that was infrequently presented (p = .20) at the center of the screen after the second button press in the main task.

At the end of the experiment, participants rated how much attention they directed to the deviant cursor movements on a 7-point scale (1 = *not at all* to 9 = *very much*).

Physiological Recording

An electroencephalogram (EEG) was recorded from 39 scalp sites using an electrode cap with Ag/AgCl electrodes. The ground electrode was fixed on the forehead. A high-pass filter of 0.016 Hz and a low-pass filter of 60 Hz were used during recording. Horizontal and vertical electrooculograms (EOGs) were recorded from the electrodes attached at the outer canthi of both eyes and above and below the left eye. The sampling rate was 500 Hz. Electrode impedance did not exceed 10 kΩ.

Data Reduction

First, we excluded anomalous trials in which the first button press did not occur within 5,000 ms, or in which the reaction time (RT) in response to a probe stimulus exceeded the mean + 2 *SD* value of that participant (3.6% of the total trials). As a behavioral measure of attentional distraction, we subtracted the mean RT in the standard trials from the mean RTs in the deviant-hit and from the RTs in the deviant-miss trials. The EEG data were re-referenced to the linked earlobes offline. A digital bandpass filter of 0.1–30 Hz was applied and ocular artifacts were corrected with the regression method. ERP waveforms were obtained by averaging the 1,000 ms period, starting 200 ms before the second cursor movement. To compare the two types of deviant trials, we subtracted ERPs in the standard trials from ERPs in the deviant-hit and deviant-miss trials. The amplitudes of the N2 and P3 were measured in the difference waves as mean amplitudes of 200–250 and 270–450 ms after the second cursor movement, respectively. For brevity, only the amplitude data at the dominant site (Cz = central midline) were reported below.

Subjective, behavioral, and ERP data were submitted to repeated measures analyses of variance (ANOVAs). Post hoc multiple comparisons were made with the Bonferroni *t* tests.

Results

Subjective Ratings

A one-way ANOVA showed a significant main effect of deviance, $F(1, 21) = 8.62$, $p < .01$. Participants reported that they had directed more attention to deviant action effects in the deviant-miss trials ($M = 5.3$, $SE = 0.3$) than in the deviant-hit trials ($M = 4.6$, $SE = 0.4$).

Behavioral Measures

The mean RTs in response to probe stimuli were 434 ms ($SE = 12$), 438 ms ($SE = 11$), and 469 ms ($SE = 16$) in the standard, deviant-hit, and deviant-miss trials, respectively. Figure 2 shows the mean behavioral delays in both deviant trials. A one-way ANOVA showed a significant main effect of the type of deviance, $F(1, 21) = 11.50$, $p = .01$. Behavioral delay was larger in the deviant-miss trials than in the deviant-hit trials. Moreover, paired *t* tests between the RTs in the deviant and standard trials showed that a significant behavioral delay occurred only in the deviant-miss trials ($p < .05$).

ERPs

Figure 3 shows the grand average ERP waveforms at the central midline electrode site (Cz). Larger ERPs were elicited in the deviant-hit and deviant-miss trials than in the standard trials. As can be seen in the difference waves, the N2 was elicited only in the deviant-miss trials. A one-way ANOVA on each amplitude measure showed a significant main effect of deviance type, $Fs(1, 21) = 67.59$ and 25.72, $ps < .001$, for the N2 and P3, respectively. The N2 and P3 were larger in the deviant-miss trials than in the deviant-hit trials.

Discussion

According to subjective reports, participants directed more attention to the unexpected action effects in the deviant-miss trials than they did in the deviant-hit trials. The deviant-miss trials caused a behavioral delay, while the deviant-hit trials did not. ERP data showed that a larger N2 component was elicited only in the deviant-miss trials. The P3 was elicited by both the deviant-hit and deviant-miss trials, although P3 amplitude was larger in the deviant-miss trials than in the deviant-hit trials.

Because the deviant-hit and deviant-miss trials occurred with an equal probability, these differences are not attributable to rarity of the event. The N2 and behavioral delay occurred simultaneously in response to a failure in goal achievement. This result suggests that

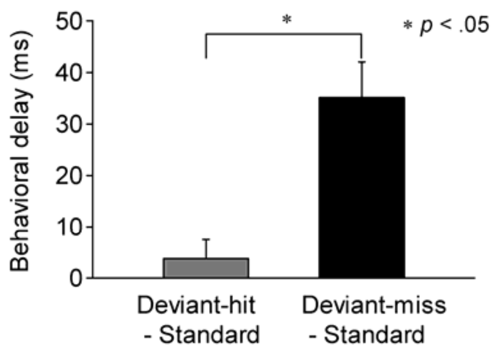

Figure 2. Means and standard errors of the behavioral delay in the probe detection task.

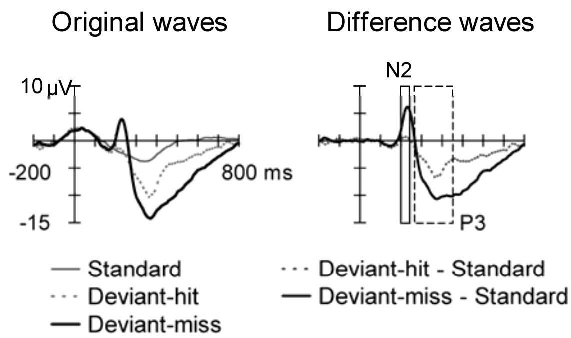

Figure 3. Grand average ERP waveforms at Cz ($N = 22$).

the N2 is a feedback-related negativity that is elicited by a worse-than-expected outcome (Holroyd & Coles, 2002). On the other hand, the P3 is sensitive to sensory deviances after action execution (Nittono, 2006). The larger P3 amplitude in the deviant-miss trials suggests that a larger amount of attention was allocated to deviant events that indicate goal failure than to harmless deviant events. In conclusion, the present study shows that a failure in goal achievement—and not the occurrence of an infrequent event—captures a user's attention and interrupts ongoing task execution.

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