The effect of response execution on P3 latency, reaction time, and movement time

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Abstract
This study examined the effect of response selection and execution on P3 latency during the performance of simple reaction time (RT) and stimulus–response compatibility tasks. Response time on these tasks was defined in terms of RT and movement time (MT). Event-related brain potentials were recorded from 67 female participants concurrently with the performance measures. On the simple RT task, the distance of the response button from the home button was varied (7, 15, and 23 cm). When stimulus evaluation demands were minimal, response execution affected P3 latency, with increased response button distance resulting in increased P3 latency. However, these movement effects were modest, and in most protocols, would not be a confounding factor. The stimulus–response compatibility task examined the interaction of stimulus evaluation demands and response requirements. RT, MT, and P3 latency were affected by stimulus congruency, whereas RT and P3 amplitude were affected by response compatibility.

Descriptors: Reaction time, Movement time, P3 latency, Simple reaction time, Stimulus–response compatibility, Eriksen task

Response time has a long history as a useful means of revealing information about mental activity (Luce, 1986). An important refinement in the measurement of response time has emerged from work with event-related potentials (ERPs). Specifically, the latency of the P3 component was promoted as a measure of stimulus evaluation time that is independent of response selection and execution processes (Duncan-Johnson, 1981; Kutas, McCarthy, & Donchin, 1977; McCarthy & Donchin, 1981). This view is widely endorsed, although there is some evidence that the sensitivity of P3 latency to stimulus processing time decreases with factors that increase response time (Verleger, 1997). For the response time measures used in the Verleger study, however, no distinction was made between response selection and response execution. More specifically, there was no systematic manipulation of response parameters that would endorse the view that P3 latency is independent of response execution, that is, the movement or motor component of the response, per se. In the present study, the influence of response execution on P3 latency, that is, the effect of the movement component of the response time measure, was explored during the performance of simple reaction time (RT) and stimulus–response compatibility tasks.

The claim that P3 latency is independent of response selection and execution is based on the following observations. When stimulus evaluation demands are increased, both response time and P3 latency tend to increase. But, when response processing demands are increased, response time is often the only measure that increases. This effect was demonstrated in a task that varied the level of semantic categorization difficulty, specifically, in the identification of synonyms. Speed and accuracy instructions were also varied. Both P3 latency and response time increased with task difficulty. Although speed instructions decreased response time, they had no affect on P3 latency (Kutas et al., 1977). Similar effects were observed on a Stroop task, in which color names were either congruent or incongruent with the color in which they were printed. Response times were increased when subjects were required to respond to incongruent stimuli, but P3 latency was not increased (Duncan-Johnson, 1981). This result also emerged in a task manipulating both noise within a stimulus and response compatibility. Response times were increased by both noise and response incompatibility. P3 latency increased substantially with noise, but to a much smaller extent with response incompatibility (Magliero, Bashore, Coles, & Donchin, 1984). Other response-related manipulations, such as hand placement (Leuthold & Sommer, 1998; Ragot & Renault, 1981) and movement direction (Fiori, Ragot, & Renault, 1992) did not influence P3 latency.

In these and similar works, response time was measured in a variety of ways, but the component structure of response time was seldom delineated. For example, response time was indexed as a
voice-activated relay (Duncan-Johnson & Kopell, 1981), as the press of a lever to the right or left (Ford, Mohs, Pfefferbaum, & Kopell, 1980), as the press of a response button, which was either directly beneath the subject’s finger/thumb (Magliero et al., 1984; McCarthy & Donchin, 1981) or at an unspecified distance away (Kutas et al., 1977), or, it was not defined (Duncan-Johnson, 1981). Response time can be decomposed to include, for example, components such as stimulus evaluation, response selection, and response execution. In research analyzing the chronometry of mental ability, it is now common practice to distinguish response time in terms of RT, the time required to evaluate a stimulus and to select a response, and movement time (MT), the time required to execute a motor response. These components can be differentiated by an apparatus making use of a home button and response buttons. RT is defined as the time from stimulus onset to the release, or lift-off from the home button, and MT is recorded as the time from this release to the subsequent press of a response button (Jensen & Munro, 1979). Because RT is affected by the information demands of the stimulus, whereas MT is not, RT is thought to be determined primarily by cognitive processing factors, and MT is thought to reflect the speed of sensorimotor processes that are required to execute the response. MT can be influenced by introducing various distances from the home to the response button, or by increasing the size of the response button (Fitts, 1954).

In experiments that differentiated RT from MT, data indicated that RT increased with increases in response processing demands, but MT did not. This result was found in studies that used stimulus–response compatibility paradigms (Frowein, 1981; Houlihan, Campbell, & Stelmack, 1994; Simon, 1969), and studies that varied the number of response alternatives (Brainard, Iby, Fitts, & Alluisi, 1962; Hick, 1952; Jensen, 1982), or emphasized speed of responding over accuracy (Houlihan et al., 1994).

In the studies described previously that demonstrated the independence of P3 latency from response processing time (e.g., Duncan-Johnson, 1981; Kutas et al., 1977; Magliero et al., 1984), response execution demands were, in general, minimal. Typically, the only required response was the depression of a response button, and no ballistic movement was required. The structure of the tasks used were also known to influence RT rather than MT. There are, in fact, few ERP studies that differentiated between RT and MT. A strong test of the hypothesis that P3 latency is a measure of stimulus evaluation time independent of response production is that factors that influence MT do not influence P3 latency. One study manipulated movement extent along with stimulus–response compatibility, and found that P3 latency was slower to the further distances (Renault, Fiori, & Giami, 1988). This effect, however, has not been replicated.

In recent work in our laboratory, P3 latency, RT, and MT measures were obtained during the performance of several elementary cognitive tasks, including simple and choice RT, physical (same–different) similarity, semantic (synonym–antonym) similarity, category matching, and a Sternberg (1966) digit recognition task that manipulated memory set size. P3 latency and RT both increased with task difficulty, but MT did not (McGarry-Roberts, Stelmack, & Campbell, 1992). In a second study, ERPs were recorded during three tasks: a Sternberg recognition task, a version of the Eriksen task (Eriksen & Eriksen, 1974) that manipulated congruency within a stimulus, and a response compatibility task. Although both P3 latency and RT increased with stimulus analysis demands, only RT increased with response incompatibility (Houlihan et al., 1994).

In both of the studies discussed above, responses were recorded from a three-button mouse, with the middle button as a home button. Although this 2-cm distance was sufficient to measure task-related variations in MT, there was no manipulation of the ballistic component of the movements.

The present study examined the relation of response execution and P3 latency by varying the motor requirements in a simple RT task, and by exploring the interactive influence of stimulus congruence and response compatibility. In the simple RT task, MT was varied by using blocks of trials that required traversing different distances to reach the response button. Stimuli were auditory tones that occurred every 3 s. Because stimuli of higher intensity are known to elicit faster response times (Cattell, 1886; e.g. Jasikowski, Rybarczyk, & Jaroszyk, 1994), but it is not known whether the effect is at the level of RT or MT, or both, two different intensities were used. Both served as equivalent signals to respond.

The stimulus–response compatibility paradigm was used to assess the effects of stimulus congruency and response compatibility on P3 latency, RT, and MT. In previous stimulus–response compatibility paradigms, RT and MT were not differentiated. With respect to P3 latency, somewhat different effects were observed depending on the nature of the response compatibility paradigm. Stimulus–response compatibility refers to the interactive effects of stimulus and response characteristics on RT. There are two main categories of stimulus–response compatibility considered in the literature. First, response incompatibility may be induced by manipulating the spatial location of the stimulus, such that stimuli on the left side of the body indicate a response on the right side of the body. This manipulation is the basis of the Simon effect, in which lateralized stimuli are used, and the task-irrelevant spatial location of the stimulus interacts to affect response time. For example, a high pitch tone, or the word “right” may signal responses to the right. When these stimuli are presented to the left ear, response times are delayed more than if they were presented to the right ear. Most researchers have found that incompatibility in Simon effect paradigms delays both response time and P3 latency (Leuthold & Sommer, 1998; Nandrino & El Massiou, 1995; Ragot, 1984; Ragot & Lesèvre, 1986; Ragot & Renault, 1981; Renault et al., 1988; Sommer, Leuthold, & Hermanutz, 1993; Valle-Inclán, 1996a, 1996b). A few studies have found no effects (Fiori et al., 1992; Mulder, Gloerich, Brookhuis, van Dellen, & Mulder, 1984; Ragot & Fiori, 1994).

The second category of stimulus–response compatibility in the literature manipulates the symbolic rather than the spatial dimension. Stimuli are not lateralized, but presented to the subjects’ midline. Response incompatibility is induced by using, for example, arrows pointing to the left, or the word “left,” and requiring a response to the right. When McCarthy and Donchin (1981) manipulated symbolic compatibility, the target stimuli were preceded by the words “same” and “opposite” to cue response compatibility. They found no effect on P3 latency. In a similar paradigm, P3 latency was found to be delayed by response incompatibility, but to a much lesser extent than response time, so that the authors concluded that P3 latency was largely unaffected by response parameters (Magliero et al., 1984). Other studies using the symbolic compatibility manipulation often report that P3 latency was delayed by response incompatibility (Christensen, Ford, & Pfefferbaum, 1996; Pfefferbaum, Christensen, Ford, & Kopell, 1986), though the result is not consistent (Houlihan et al., 1994; Pfefferbaum et al., 1986). The present study used a compatibility cue that preceded the stimuli, the words “same” and “opposite,” as did McCarthy and Donchin (1981), and Magliero et al. (1984). In the present case, however, the response time parameters are precisely defined in terms of RT and MT.
EXPERIMENT 1

Method

Participants
Sixty-seven female university students volunteered for the experimental sessions. The age of the participants ranged from 18 to 30 years (M = 22 years, SD = 3). Of the 67 participants, 50 completed both the simple reaction time and stimulus–response compatibility tasks. Seven participants took part in only the simple RT task (n = 57) and 10 others in only the stimulus–response compatibility task (n = 60).

All participants were right handed, had normal hearing (thresholds ≤ 15 dB SPL when tested at 500 Hz), had normal or corrected-to-normal vision, no motor impairments, and were not taking any medication other than oral contraceptives.

Response Apparatus
A response box was constructed with a home button, and response buttons to the left and right of the home button. RT was defined as the time from target stimulus onset to the release of the home button, and MT as the time from the release of the home button to the press of a response button. In the simple RT task, the response buttons were located at 7, 15, or 23 cm (angled at 30, 65, and 75°, respectively) to the left of the home button. The stimulus–response compatibility task used the home button, and the two nearest response buttons, 7 cm to the left and right of the home button. Response buttons were circular and 1.5 cm in diameter. Templates were used to reveal only the buttons used in that block of trials and to mask the unused buttons. The same finger that was kept on the home button was used for responding.

Procedure
Participants were seated 0.5 m in front of a computer monitor in a sound-attenuated room. They were instructed to continually depress the home button until the signal to respond was given.

Simple Reaction Time Task
The requirement to respond was signaled by the presentation of target tones, 500 Hz, at either 70 or 85 dB SPL, with a duration of 105 ms and a rise and fall time of 5 ms. The intertrial interval, from the onset of one trial to the onset of the subsequent trial, was 3,000 ms. Four conditions consisting of 120 trials were presented, with intensities presented in random order with equal probability within each block of trials. In the first condition (0 cm), participants were required to simply lift-off from the response button. In the other three conditions, the response button was located either 7, 15, or 23 cm from the home button. The order in which the four distances (0, 7, 15, 23 cm) were presented was counterbalanced across participants.

Participants were instructed to keep their gaze on the particular response button being used, and to guide their movements back to the home button by use of peripheral vision. Visual inspection of online electrooculogram (EOG) was used to verify that participants complied with these instructions.

Stimulus–Response Compatibility Task
The stimulus array comprised a set of arrows presented in the center of the monitor in black characters against a white background. The arrow arrays were either congruent, that is, all pointing in the same direction (> > > > > or < < < < <) or incongruent, with the middle arrow pointing opposite to the flanking arrows (> > < < > or < < > > <). Participants were instructed to focus on the middle arrow. The stimulus array was preceded by an instructional cue word, indicating whether the response was to be compatible or incompatible with the direction of the middle arrow. If the cue word was “SAME,” participants responded by pressing a response button located in the same direction as the middle arrow pointed (compatible response). If the cue word was “OPPOSITE,” participants responded by pressing the response button located in the direction opposite that of the middle arrow (incompatible response). Thus, this study had a 2 × 2 factorial design, including congruent arrays with (a) compatible and (b) incompatible instructions, and incongruent arrays with (c) compatible and (d) incompatible instructions.

The cue word was presented for 300 ms, followed by a 200 ms pause (blank screen), then the target stimulus (arrow array) was presented for 900 ms. The next cue stimulus appeared 1 s later resulting in a trial-to-trial interval of 2,400 ms. The presentation order of stimulus conditions was randomized, but the same sequence was presented to each participant. Each of the four conditions was presented 150 times, for a total of 600 trials. A recess of 2–5 min was given after every 200 trials. Participants were given practice trials in blocks of 25 to familiarize them with the paradigm. These were repeated until 75% accuracy was attained.

Participants were instructed to keep their gaze on the center of the display monitor, and to avoid looking at the response box. The participants did not report any difficulty with these instructions.

In both tasks, RT and MT scores for each participant were the mean median times for each condition. Only trials to which a correct response was made were included in the data analyses.

Electroencephalogram (EEG) Recordings
The EEG was recorded from Ag/AgCl electrodes affixed to the midline frontal (Fz), central (Cz), and parietal (Pz) scalp sites. The horizontal EOG was recorded from electrodes placed on the outer canthi of each eye. The vertical EOG was recorded from electrodes placed on the supra- and infraorbital ridges of the left eye. The reference electrode was on the left mastoid. Inter-electrode impedances were below 2 kΩ. The high filter was set at 30 Hz, and the time constant at 2 s. The EEG and EOG were sampled at 512 Hz and stored continuously to hard disk. All recordings were performed with InstEP software (Ottawa, Ontario, Canada). Prior to averaging, the data were corrected for eye movement artifacts (Woestenburg, Verbaten, & Slangen, 1983). Offline, the data were further digitally filtered with a high filter set at 10 Hz. The digital filter operated in the frequency domain using an inverse fast Fourier transform (FFT) algorithm. Single trials were reconstructed beginning 100 ms before stimulus onset and continuing for 1,000 ms following onset. Single trials were sorted and averaged according to electrode location, stimulus category, and response accuracy. Only trials having correct detection were included in further analyses. P3 amplitude was measured relative to a 100-ms prestimulus baseline. In the case of the stimulus–response compatibility task, the prestimulus baseline was set at 100 ms before the onset of the arrow array. The amplitude of the P3 wave was scored for each participant by determining the maximum amplitude between 275 and 550 ms.
at the Pz electrode site. The latency was measured at the mean maximum amplitude of the P3 wave.\footnote{One reviewer raised the issue of latencies derived from averaged ERPs versus from single trials. In this study, the latency of the P3 wave was measured at the mean maximum amplitude in the averaged ERP waveform. An alternative procedure for determining P3 latency is to record the latency at maximum amplitude on single trials and then average these values. The use of data from averaged waves instead of from single-trial procedures has been criticized on the basis that P3 latency from averaged waveforms is a biased measure that may yield larger experimental effects than single trial procedures. Use of data from averaged waves instead of from single-trial procedures has recently been reviewed by Sussman & Polich, 1989; Möcks, Köhler, Gasser, & Pham, 1988. This may be one reason why the mean latency in single-trial data is often later than in the averaged data. If noise is inadvertently included in single-trial data, the result is a shift of the mean towards the midpoint of the analysis epoch (Fein & Turetsky, 1989).}

Results

Simple RT Task

The objective of this simple RT task was to examine the effects of response execution processes on P3 latency and amplitude by manipulating the distance that the participant was required to traverse to complete the response. The impact of response button distance on P3 latency and amplitude was evaluated.

Data analysis. For the simple RT task, RT, MT, and P3 data were analyzed using a two-way analysis of variance (ANOVA), with repeated measures on distance (0, 7, 15, and 23 cm) and intensity (70, 85 dB SPL) factors. The effects of the order in which the response button distances were presented were analyzed in a three-way ANOVA, with order as a between-subjects factor, and repeated measures on distance (7, 15, and 23 cm) and intensity (70, 85 dB SPL) factors. The Greenhouse–Geisser epsilon was used to correct degrees of freedom, and only corrected significance levels are reported. Post hoc analyses were conducted using Tukey’s honest significant difference test.

Orthogonal trend analyses were also conducted on RT and P3 data, as tests of the linear component of the distance factor.

Order. There were no significant main effects or interactions related to the order in which the response button distances were used (F < 1).

Performance measures. Figure 1 shows RT, MT, and P3 latency data for the simple RT task. The RTs to the simple lift-off (0 cm condition) were significantly faster than the RTs that were followed by a button press, F(3,165) = 5.26, p < .007, η = .057, but the button press conditions did not differ among themselves. This effect has been attributed to the additional motor programming required to press a button accurately (Jensen, 1982). Orthogonal trend analysis verified that the linear component of the distance effect was not significant, F(1,56) = 2.02, p < .16.

RTs to the 85-dB stimuli (276 ms) were faster than to the 70-dB signal stimuli (288 ms), F(1,55) = 39.36, p < .001. The interaction between stimulus intensity and response button distance was not significant (F < 1).

Responses were more accurate to the closer distances than to the further distances (98, 97, and 96% for 7, 15, and 23 cm, respectively), F(2,110) = 6.02, p < .003, and more accurate to the 70-dB tones (97.5%) than to the 85-dB tones (97.1%), F(1,55) = 4.82, p < .03. The interaction between stimulus intensity and response button distance was not significant (F < 1).

As expected, MT increased substantially with increased distance to the response button, F(2,112) = 261.4, p < .001, ε = .93. Further, the velocity of the movement (cm/s) also increased as response button distance increased, from 42 cm/s at 7 cm, to 65 cm/s at 15 cm, to 84 cm/s at 23 cm. This difference established that the ballistic component of the movements increased with increasing response button distance. There was no effect of stimulus intensity on MT (F < 1), nor was there any interaction between stimulus intensity and response button distance (F < 1).

ERP measures. The scalp distributions of the P3 waves followed a linear increase in amplitude from frontal to parietal midline sites. Because the P3 component was not visible consistently in the individual records of the simple lift-off (0 cm) condition, it was not scored. The following data are from the conditions in which the lift-off was followed by a button press.

P3 latencies elicited by the 85-dB tones were faster than those elicited by the 70-dB tones (378 vs. 396 ms), F(1,56) = 28.85, p < .0001. Similar intensity effects were observed previously between stimulus intensity and P3 latency (Papanicolau, Loring, Raz, & Eisenberg, 1985; Sugg & Polich, 1995).

P3 latency was also influenced by response button distance, F(2,112) = 10.54, p < .00007, ε = .84. Post hoc analyses revealed that the latencies in the 7-cm (372 ms) and 15-cm (386 ms) conditions were faster than in the 23-cm (403 ms) condition. Orthogonal trend analysis verified that the linear component of the distance effect was significant, F(1,56) = 14.6, p < .0004. There was no interaction between distance and stimulus intensity, F(2,112) = 1.63, p < .20. From these data, response execution demands are seen to influence P3 latency, with increased distance resulting in increased latency. Because both MT and P3 latency increased with increasing response button distance, correlations between these measures were calculated. No significant correlations were observed at p < .05. This lack of correlation indicates that those individuals who had faster MTs are not the same individuals who had faster P3 latencies.

As is shown in Figure 1A, P3 latency was longer than RT across all distance conditions. This effect is similar to the pattern of effects observed in two other simple RT paradigms that measured RT as lift-off time (McGarry-Booth et al., 1992; Ritter, Simson, & Vaughan, 1972). If response time were recorded in an undifferentiated manner, as RT + MT, P3 latency would precede RT. This configuration is shown in Figure 1B, where MT is plotted with RT as its zero point.

The P3 amplitudes elicited by the 85-dB tones (6.91 μV) were not significantly larger than those elicited by the 70-dB tones (6.3 μV), F(1,56) = 3.68, p < .06. Although there was an observable trend with P3 amplitudes increasing with increasing distance, ANOVA results revealed that this trend was not significantly different, F(2,112) = 2.84, p < .06, ε = .86. Orthogonal trend analysis also revealed that the linear component was not significant, F(1,56) = 2.91, p < .09. There was no interaction between distance and stimulus intensity, F(2,112) = 1.5, p < .23.
Although a P3 component at approximately 380 ms was visible in individual waveforms, due to the large number of subjects and the large interindividual variability, the response button distance effect on P3 latency was obscured in the grand-average waveforms. Examples of individual waveforms are presented in Figure 2. These data are comparable to those reported by Falkenstein, Hohnsbein, and Hoormann (1993), McGarry-Roberts et al. (1992), and Ritter et al. (1972), using similar simple reaction time paradigms.

The finding that P3 latency varies with response button distance was somewhat surprising, as it seems to indicate that P3 latency is not independent of response execution demands. This effect may only emerge when stimulus evaluation demands are minimal, as in the present case. Whether this response execution effect would be maintained under conditions of greater stimulus evaluation demands was not certain. Accordingly, an additional experiment was carried out using a standard auditory oddball task.

Stimulus–Response Compatibility Task
The objective of this stimulus–response compatibility task was to examine the interaction of stimulus evaluation demands with response selection demands on the P3 wave. Of particular interest was the effect of these manipulations on the independence of P3 latency and response time when RT was differentiated from MT.

For this task, response button distance was kept constant at the minimum distance on the response box, that is, 7 cm.

Data analysis. For the stimulus–response compatibility task, RT, MT, and ERP data were analyzed with two-way ANOVAs, with repeated measures on stimulus congruency (congruent, incongruent) and response compatibility (compatible, incompatible) factors. Post hoc analyses were conducted using Tukey’s honest significant difference test.

Performance measures. Figure 3 presents means from performance and P3 latency data. RTs to congruent arrays were faster than to incongruent arrays, $F(1,59) = 177.09, p < .0001$. RTs under compatible response instructions were also faster than under incompatible response instructions, $F(1,59) = 43.72, p < .0001$. There was an interaction between stimulus congruency and response compatibility, $F(1,59) = 19.04, p < .0001$, such that the increase in RT latency was larger when response were compatible.

Within the MT measures, congruent stimulus arrays elicited faster MTs than incongruent arrays, $F(1,59) = 21.34, p < .001$. There was also an interaction with response compatibility, $F(1,59) = 5.31, p < .025$, such that the increase in MT latency due to stimulus incongruency was larger when responses were compatible than when they were incompatible.
Figure 2. Waveforms from the simple reaction time task for 12 individuals. Waveforms show averages for each response button distance with the 85-dB stimuli. P3s are indicated by arrows.
Responses were more accurate to congruent arrays (94%) than to incongruent arrays (91%), $F(1, 59) = 24.0, p < .0001$, and more accurate under compatible instructions (94%) than under incompatible instructions (92%), $F(1, 59) = 12.75, p < .0007$. The interaction was not significant, $F(1, 59) = 2.5, p < .12$.

These behavioral results suggest that both RT and MT are delayed by incongruent arrays, but only RT is delayed by response incompatibility. Although the delay in MT attributable to stimulus incongruence is slight, the delay does suggest that MT may not be a pure measure of motor execution.

**ERP measures.** Figure 4 presents grand-average waveforms to the congruent and incongruent arrow arrays, and Figure 5 for compatible and incompatible response instructions. Congruent arrays elicited larger P3 amplitudes than did incongruent arrays (means were $3.73$ and $2.53 \mu V$, respectively), $F(1, 59) = 23.18, p < .0001$. Also, instructions for compatible responses elicited larger P3 amplitudes than did incompatible response instructions (means were $4.59$ and $1.67 \mu V$, respectively), $F(1, 59) = 76.34, p < .0001$. No interaction was observed ($F < 1$). These results are consistent with those reported by Bashore (1990) and Magliero et al. (1984), and with the view that P3 amplitude varies inversely with task difficulty (e.g., Picton, 1992).

Congruent arrays elicited faster P3 latencies (362 ms) than did incongruent arrays (411 ms), $F(1, 59) = 45.26, p < .0001$. There were no significant differences between the compatible and incompatible response conditions $F(1, 59) = 1.74, p < .19$, nor were there any interactions with the compatibility factor, $F(1, 59) = 1.97, p < .17$.

These ERP data endorse the view that P3 latency is affected by stimulus evaluation processes, but not by response selection processes.

![Figure 3](image1.png)

**Figure 3.** Means and standard errors for P3 latency, reaction time (RT), and movement time (MT) on the stimulus–response compatibility task. RTs, MTs, and P3 latencies are faster for congruent than incongruent arrays. RTs are faster for compatible than incompatible response instructions.

![Figure 4](image2.png)

**Figure 4.** Grand-average waveforms recorded at Fz, Cz, and Pz showing P3 latencies for congruent and incongruent arrays on the stimulus–response compatibility task. P3 is indicated by an arrow.
EXPERIMENT 2

As previously noted, the response button distance effect was obscured in the grand-average waveforms of the simple RT task. Also, it was clear that the response button distance effects were observed under conditions in which stimulus evaluation demands were minimal. Another experiment was conducted using a standard oddball paradigm to increase the prominence of the P3 wave in grand-average waveforms, and to determine whether the effects of increased response execution demands on P3 latency would be maintained when stimulus evaluation demands were increased.

Method

Participants
Seven female university students volunteered their participation. The age of the participants ranged from 18 to 23 years ($M = 20$ years, $SD = 1.7$). All participants were right handed, had normal hearing (thresholds $\leq 15$ dB SPL when tested at 500 and 1500 Hz), no motor impairments, and were not taking any medication other than oral contraceptives.

Procedure
Participants were seated comfortably with headphones in a sound-attenuated room. They were instructed to continually depress the home button until the signal to respond was given. Stimuli were auditory tones with an intertrial interval of 3,000 ms. All tones were presented at 85 dB, 105 ms in duration, with a rise and fall time of 5 ms. Rare tones were presented at 500 Hz randomly among a series of 1500-Hz standard tones in a ratio of 1:4. Three distance conditions were presented, each consisting of 220 trials, with the response button located either 7, 15, or 23 cm from the home button. The order in which the three distances were presented was counterbalanced across participants. Participants were instructed to respond to the rare tones by lifting off the home button and pressing a target button, and to avoid responding to the frequent tones. These instructions transform the task into a go/nogo task, rather than a simple RT task. All performance and ERP data are based on trials in which the rare stimuli were presented.

Results

Performance Measures
Response accuracy at the 7-cm response button distance (93%) did not differ significantly from the 15-cm condition (100%), or the 23-cm condition (97%), $F(2,12) = 1.8$, $p < .21$. Figure 6 presents the means for the performance and P3 latency data in the standard oddball paradigm. There was no significant main effect of response button distance on RTs, $F(2,12) = 3.47$, $p < .10$, $\epsilon = 0.61$. Orthogonal trend analysis verified that the linear component of the distance effect was not significant, $F(1,6) = 1.67$, $p < .24$. There was a significant effect of response button distance on MT mea-
The oddball task above was different from the simple RT task in both stimulus presentation and response requirements. The oddball task had rare and frequent tone stimuli presented in a ratio of 1:4, whereas the simple RT task had equiprobable stimuli. Also, the oddball task required participants to respond to only the rare tones, essentially being a go/nogo task, whereas the simple RT task required a response to each tone. To determine which of these discrepancies between the tasks led to the diminution of the effect of response button distance on P3 latency, an intermediate task was adopted, in which the oddball task’s stimulus ratio was maintained, but the participants were required to respond to all stimuli. In this way, stimulus evaluation requirements were once again minimized, but the stimulus ratio might result in more prominent P3 waves than the simple reaction time task.

**Method**

**Participants**

Seven female university students volunteered their participation. The age of the participants ranged from 19 to 22 years ($M = 20$ years, $SD = 1.3$). All participants were right handed, had normal hearing (thresholds ≤ 15 dB SPL when tested at 500 and 1500 Hz), no motor impairments, and were not taking any medication other than oral contraceptives.

**Procedure**

Procedure and stimuli were as in the oddball task of Experiment 2, except that participants were instructed to respond to all the tones by lifting off the home button and pressing a target button. All performance and ERP data were based on trials in which the rare stimuli were presented.

**Results**

**Performance Measures**

Response accuracy was 94% at 7 and 15 cm, and 95% at 23 cm, a nonsignificant difference ($F < 1$). Responses to both rare and frequent tones were 94% accurate. The interaction of response button distance with tone rarity was not significant, $F(2,12) = 3.1, p < .05$.

Figure 8 presents performance and P3 latency means from this task. There was no significant main effect of response button distance on RTs ($F < 1$). Orthogonal trend analysis confirmed that the linear component of the distance effect was not significant ($F < 1$). MT, of course, increased substantially with increasing distance to the response button $F(2,12) = 55.38, p < .00001, \epsilon = 0.99$. An increase in velocity was observed as in Experiments 1 and 2. Velocity was 41, 65, and 81 cm/s at 7, 15, and 23 cm, respectively.

**ERP Measures**

Figure 9 presents grand-average waveforms for both frequent and rare stimuli at each of the three distances. Statistical analyses were performed on the data from the rare stimuli. The effect of response button distance on P3 latencies approached statistical significance, $F(2,12) = 3.62, p = .09, \epsilon = 0.74$. Tukey’s post hoc analysis confirmed that the latencies for the 23-cm condition were significantly longer than for the 7-cm condition. Orthogonal trend analysis verified that the linear component of the distance effect was significant, $F(1,6) = 7.40, p < .03$. There was no significant effect of response button distance on P3 amplitudes ($F < 1$).

**Discussion**

The view that P3 latency is a measure of stimulus evaluation independent of response selection and execution is widely endorsed. The objectives of the study were to independently manipulate stimulus evaluation, response selection, and response execution demands to determine their effect on P3 latency. To that end, a simple RT task was used in which response execution, or the motor component of responding, was systematically varied while stimulus evaluation demands were kept minimal. Further, a stimulus–response compatibility task was used, in which stimulus evaluation demands were varied by using congruent and incongruent stimulus arrays, and response selection demands were varied by using compatible and incompatible response instructions.

A unique aspect of this study was the differentiation of response time into two components, RT and MT. RT was defined as the time from stimulus onset to the lift-off from a home button, whereas MT was defined as the time from lift-off to the press of a target button. The recording of RT as a lift-off time, rather than as a button press, allows the measurement of response selection processes to be separated from response execution processes, and also
allows MT to be quantified. In the simple RT paradigm, RT was noted to precede P3 latency. This observation has been made whenever RT was measured as a lift-off in a simple RT task (McGarry et al., 1992; Ritter et al., 1972). This underscores the importance of differentiating RT and MT when the focus of the analysis is on RT and P3 latency relations.

As observed in previous work, the P3 amplitudes in the simple RT task tended to be somewhat smaller than those observed in a typical oddball task. The morphology of the waveform was comparable to that observed by Ritter et al. (1972) using similar stimulus parameters and task requirements. Further, the latencies observed were comparable to those of Falkenstein et al. (1993) and McGarry-Roberts et al. (1992).

The most striking finding of this study was that P3 latency increased with increasing response button distance. This result was observed in the simple RT paradigm, in which the ballistic movement requirements were substantial. However, all tones served as equivalent signals to respond, and as such, stimulus evaluation demands were minimal. It was unclear whether this effect would be sustained if stimulus evaluation demands were increased.

To investigate whether the response button distance effect on P3 latency would be maintained under conditions of greater stimulus evaluation demands, the manipulation of response button distance was applied to the standard oddball paradigm. When only the rare tones were designated as target stimuli, that is, when targets were to be discriminated from nontargets, the response execution effect on P3 latency was not maintained. However, when stimulus evaluation requirements were again reduced, that is, when both the rare and frequent tones were designated as targets, the response execution effect emerged again, as P3 latency increased with increasing response button distance.

**Figure 7.** Grand-average waveforms for rare stimuli on the oddball task when only rare tones are designated targets. P3 is indicated by an arrow.
In this simple RT task with large, ballistic movements required, the most demanding aspect of the task was the physical execution of the response, not the stimulus evaluation. In this instance, it is plausible that P3 latency involves the analysis of the now task-relevant proprioceptive or kinesthetic stimuli, the movement itself. P3 latency is perhaps dependent on the analysis of the movement-related sensory stimuli that occurs when a motion is being guided toward a target. Alternatively, P3 latency may be indexing the completion of the movement execution. Further research in which stimulus evaluation demands are gradually increased is warranted, perhaps in an experiment that uses variable interstimulus intervals to introduce a degree of temporal uncertainty and to increase the amplitude of the P3.

In the stimulus–response compatibility task, consistent effects of stimulus congruency were present in the RT, MT, and P3 latency measures, confirming that incongruent arrays increase stimulus evaluation time. These results conform to those found in previous work when the Eriksen flanker task was used (Bashore, 1990; Houlihan et al., 1994).

**Figure 8.** Means and standard errors for P3 latency, reaction time (RT), and movement time (MT) on the oddball task when all tones are designated targets. Both P3 latency and MT increase with increasing response button distance.

**Figure 9.** Grand-average waveforms for rare and frequent stimuli on the oddball task when all tones are designated targets. P3 is indicated by an arrow.
Congruent arrays elicited faster MTs than did incongruent arrays. This finding is a replication of the effect obtained by Houlihan et al. (1994). Although the MTs elicited by congruent and incongruent arrays differed by only 9 ms, the consistent pattern of the results both within and between experiments suggests that MT is minimally affected by ongoing stimulus evaluation.

Although RT was slowed by response incompatibility, P3 latency was not. In the studies that manipulated symbolic compatibility, some found that P3 latency was affected, whereas others did not. A useful distinction within these studies are those that use implicit compatibility instructions and those that use explicit instructions, referring to whether the cue is separate from the stimulus or part of the stimulus. Specifically, McCarthy and Donchin (1981) and Magnier et al. (1984) used explicit instructions that preceded the target stimuli, and found that RT was affected much more than P3 latency. In contrast, Christiansen et al. (1996) used an implicit part of the target stimulus, letter case, to cue compatibility, and found that P3 latency was delayed by cues to respond incompatibly. The many studies that use the Simon effect also manipulate compatibility by implicit cues, in their case, the spatial location of the stimulus. The effects on P3 latency that are observed when using implicit compatibility cues may be attributable to response compatibility being assessed simultaneous with the presentation of the stimulus. This temporal overlap may result in an apparent P3 latency effect (Verleger, 1997). When response compatibility cues are external to the stimulus, preliminary compatibility processing can be carried out separate from stimulus evaluation. Regardless of whether the compatibility cues are implicit or explicit to the stimulus, however, response selection cannot begin until the presentation of the arrow array. As a result, the design that uses external compatibility cues allows for a more discrete test of the independence of P3 latency from response selection processes.

The results of the stimulus–response compatibility paradigm concur with the view that response selection processes are independent of P3 latency. The results of the simple RT tasks, however, suggest that this conclusion should be tempered, as motor execution can influence P3 latency. This effect, however, is observed only when stimulus evaluation demands are minimal. Increasing stimulus evaluation demands even slightly, as in the typical oddball task, is sufficient to mask the motor execution effects on P3 latency. In general, motor execution processes would not be considered a confounding factor in most P3 studies.

Distinguishing RT and MT in RT tasks merits some consideration. RT provides a discrete measure of cognitive processing activity that precedes motor execution. Combining these measures with P3 latency studies permits an assessment of the independence of P3 from both response selection and response execution processes.

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