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On the Biological Bases of Extraversion:
Sensory and Motor Considerations

by

© Cynthia Doucet

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All labyrinths are one labyrinth; all mazes meet in the center.

- Neil Gaiman

If things are muddled, describe the muddle.

- Bob Stelmack

Grasp the subject, the words will follow.

- Cato the Elder

Abstract

Using the Eysenck Personality Questionnaire-Revised, 67 female subjects were classified into three extraversion groups, introverts, ambiverts, and extraverts. Event-related brain potentials were recorded concurrently with response time measures as participants performed simple reaction time and stimulus-response compatibility tasks. Response time was differentiated into reaction time and movement time. The auditory simple reaction time task varied motor task requirements by varying the distance of the response button from the home button, and also varied stimulus intensity. The stimulus-response compatibility task varied stimulus evaluation demands by using arrays comprised of a middle arrow with flankers either congruent or incongruent with its direction, and varied response requirements by using instructions indicating whether the response was compatible or incompatible with the direction of the middle arrow. There was no overall effect of extraversion group on P3 latency or RT. Group differences were apparent, however, on measures of N1 amplitude, with introverts displaying larger amplitudes than extraverts. This result is consistent with introverts' greater reactivity to stimulation than extraverts. Behaviourally, on both tasks, extraverts tended to have faster movement times than introverts. Further, on the simple reaction time task, the magnitude of the difference in movement time between introverts and extraverts remained constant across the response button distances, indicating that the differences are occurring in the initial phase of the movement, rather than in the ballistic phase. These results are in accordance with a sensory-motor theory of extraversion that underscores the importance of reactivity to sensory stimuli, and speed of motor responding.

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Curriculum Studorium

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Table of Contents

Historical Overview

One of the most heuristic theories of personality was derived from Eysenck's (1967) *The Biological Basis of Personality*. Extraversion, as Eysenck defined it, is a dimensional trait derived from factor analysis of questionnaire items, and is characterised by a disposition towards sociability (ease of mixing with people) and preference for physical activity. The understanding of extraversion is instrumental in predicting social and psychiatric behaviour, and is successfully exploited in personnel selection.

In Eysenck's theory, introverts were proposed to have higher levels of cortical arousal than extraverts. This arousal construct was conceived as an explanatory bases for observed differences in extraversion. For the next few decades, research that had the arousal construct as its basis proceeded. In a review of this extensive literature (Stelmack, 1990, 1997), two effects consistently emerged. First, extraverts initiate the expression of motor activity faster than introverts, an effect that converges well with the preference of extraverts for spontaneous and physical activity. Second, introverts exhibit greater sensitivity (or reactivity) to punctate, physical stimulation than extraverts. This sensitivity may explain their avoidance of social situations, which are composed of a multitude of sights and sounds. In short, there is evidence that sensory and motor processes may be implicated in individual differences in extraversion.

Introduction

In the present research, individual differences in extraversion were examined in relation to sensory, motor, and cognitive processes. Two tasks were used, an auditory simple reaction time task, and a stimulus-response compatibility task. Event-related brain potentials were recorded concurrently with response time measures. By using an apparatus with a home button and response button(s), the response time measure was differentiated into reaction time and movement time. Reaction time (RT) was defined as the time from stimulus onset to the lift off from a home button, while movement time (MT) was defined as the time from lift-off to the press of a response button (Jensen & Munro, 1979).

The most innovative aspect of the simple reaction time task was the manipulation of movement extent. By using blocks of stimuli, each requiring the press of a response button at a different distance from the home button, the influence of the ballistic component of movement could be assessed. If the magnitude of the difference in MT between introverts and extraverts increases with increasing response button distance, differences could be attributed to physiological processes involved in ballistic movement. Also, previous examinations of whether extraverts have faster reaction times than introverts have yielded mixed results. The distinction of RT from MT allows us to determine whether a difference is due to the RT, or MT component, or perhaps both.

In both the simple reaction time and the stimulus-response compatibility tasks, event-related potentials (ERPs) were recorded concurrently with RT and MT. The simple reaction time task varied stimulus intensity in order to examine individual differences in sensory reactivity. As the amplitude of the N1 component of the ERP increases with increases in stimulus intensity, it was used as an index of sensory reactivity.

The stimulus-response compatibility task was chosen to explore whether there are differences in the cognitive processing speed of introverts and extraverts. The task varied stimulus evaluation requirements by using arrays of arrows in which the middle arrow was flanked by arrows pointing in the same, or in the opposite direction. The task also varied response selection demands by using instructions indicating that the response was to be compatible or incompatible with the direction of the middle arrow. The latency of the P3 component of the ERP has been shown to increase with increases in stimulus evaluation demands. In this study, P3 latency was used as an index of speed of cognitive processing. If extraversion is mediated at a cortical level related to cognitive processing, differences should be apparent in the P3 latency measure.

The following chapters present an analysis of this project in three stages. The first chapter focuses on individual differences in extraversion on the behavioural performance measures of RT and MT. The objectives were to explore individual differences in extraversion in response selection and speed of motor responding. Extraverts and introverts did not differ in response selection processes, as indexed by RT, but the MTs of extraverts were consistently approximately 40 ms faster than those of introverts. The constant magnitude of the difference, regardless of movement extent or task difficulty, led us to conclude that the individual differences in extraversion were apparent in the initiation of the movement, but not in the ballistic phase of the movement. This chapter was published under the title "Movement time differentiates extraverts from introverts" in *Personality and Individual Differences* (1997) volume 23, pp. 775-786. The second chapter focuses on the methodological issue of the independence of P3 latency from response execution processes. The claim that P3 latency is independent of response selection and response execution is based largely on studies that manipulated only response selection parameters. The data from the present study provided a good opportunity to examine the independence of P3 latency from both response selection and execution processes. The surprising finding, that P3 latency increased with increasing response button distance, was scrutinized with supplementary experiments, with the conclusion that movement extent only influences P3 latency when stimulus evaluation demands are minimal, as in a simple reaction time task. This chapter was recently accepted for publication under the title "The effect of response execution on P3 latency, reaction time and movement time" in *Psychophysiology*. The third chapter examines individual differences in extraversion in regards to sensory reactivity and speed of cognitive stimulus processing. The objectives of this analysis were to explicate the sensory and motor bases of individual differences in extraversion using behavioural measures and ERPs to illuminate the distinction between sensory reactivity, speed of cognitive processing, and speed of motor responding. Sensory reactivity was indexed by N1 amplitude, and speed of cognitive processing by P3 latency. Introverts were found to have larger N1 amplitudes, an effect consistent with greater sensory reactivity. No remarkable differences between introverts and extraverts were evident in P3 latency. These effects are discussed in relation to hypothesized differences in cortical arousal, and in terms of the peripheral bases of the sensory and motor differences observed in individual differences in extraversion. The manuscript for this analysis is currently in progress, and will be submitted for publication in the *Journal of Personality and Social Psychology*.

Chapter 1

Movement Time Differentiates Extraverts from Introverts

Abstract

Sixty-seven female subjects who were classified on the Eysenck Personality Questionnaire-Revised were compared on simple reaction time and stimulus-response compatibility tasks. Response time on these tasks was defined in terms of reaction time (RT) and movement time (MT). On the simple reaction time task, the distance from the target button from the home button was varied. The stimulus-response compatibility task examined the interaction of Extraversion with stimulus evaluation demands and response requirements. For both tasks, and across all conditions, the MTs of extraverts were faster than those of the introverts, but no relation with RT was observed. These results support the view that individual differences in Extraversion are influenced by differences in fundamental motor mechanisms.

There is abundant evidence establishing introverts as more reactive than extraverts to physical stimulation. In relation to extraverts, introverts exhibit lower auditory thresholds (Stelmack & Campbell, 1974), lower pain thresholds (Schalling, 1971), greater sensitivity to noise (Dornic & Ekehammar, 1990), and larger psychophysiological responses to stimuli (Smith, Concannon, Campbell, Bozman & Kline, 1990; Stelmack, 1990). These differences are understood in terms of the introverts' higher level of cortical arousal (Eysenck, 1967) or arousability (Claridge, 1967) than extraverts, or more directly, in terms of their greater sensory sensitivity (Stelmack, 1990). However, there is another body of evidence regarding Extraversion and motor expression that is not easily explained by differences in cortical arousal. For example, extraverts showed more frequent rest pauses on tapping tasks (Eysenck, 1964), greater reminiscence on pursuit rotor tracking tasks (Eysenck & Frith, 1977), and reduced levels of monosynaptic reflex recovery compared to introverts (Pivik, Stelmack & Bylsma, 1988). Such findings cannot be explained by cortical arousal, and suggest that individual differences in Extraversion may be referred to fundamental motor processes. This hypothesis is examined in the present study by using simple reaction time and stimulus-response compatibility tasks. Response times are measured by differentiating reaction time (RT) and movement time (MT).

The traditional measure of response time includes the time from stimulus onset to the press of a target button. However, reaction time (RT) can be measured independently of movement time (MT) by an apparatus making use of a "home" button. RT is recorded as the time from stimulus onset to the release of the home button, while MT is recorded as the time from this release to the subsequent press of a target button (Jensen & Munro, 1979).

It has been established that RT and MT are differentially affected by experimental parameters. RT is an index of cognitive processes and includes time relating to stimulus classification or evaluation, response selection, and programming the execution of motor movements (Theios, 1975; Welford, 1960). Evidence supporting this is derived from studies that manipulated stimulus parameters (Crossman, 1955; Nickerson, 1966; Sternberg, 1966; Thurmond & Alluisi, 1963), response sets, for example speed-accuracy trade-offs (Fitts, 1966) or stimulus-response compatibility (Fitts & Deininger, 1954), and motor execution complexity (Jensen, 1982; Klapp, 1975).

Concerning stimulus evaluation, RT increases as a function of the amount of information in the stimulus. For example, increasing the number of elements in a stimulus set increases response time (Nickerson, 1966; Sternberg, 1966). When stimulus discriminability was decreased by increasing similarity between stimulus alternatives, response times increased (Crossman, 1955; Thurmond & Alluisi, 1963). Response times also increase as the number of target alternatives increase (Brainard, Irby, Fitts & Alluisi, 1962; Hick, 1952). MT, however, shows virtually no change (Jensen, 1982).

Regarding response bias, instructions emphasizing accuracy elicit longer RTs than those emphasizing speed (Fitts, 1966; Hick, 1952). Measures of MT followed a similar pattern, but were not statistically significant (Houlihan, Campbell & Stelmack, 1994). Stimulus-response compatibility also affects RT. Stimulus-response compatibility is a concept that uses the pairing of stimuli and responses to explain why some tasks are easier than others (Fitts & Deininger, 1954). The compatibility of a relationship is based on similarities and correspondences within the ensemble (Kornblum, Hasbroucq & Osman, 1990). Compatible response instructions elicit shorter RTs than incompatible response instructions (Fitts & Deininger, 1954), but have no effect on MT (Houlihan et al., 1994; Simon, 1969).

Concerning motor execution, RT is faster when only the lift-off is required, rather than when the lift-off is to be followed by the press of a target button (Jensen, 1982). This suggests that when a target press is required, RT is longer because of the time needed to plan for the direction and speed of the movement. Some research has been carried out on the influence of various MT subcomponents on RT, including the amplitude of the initial impulse (Glencross, 1972; Klapp, 1975), movement duration (Klapp & Erwin, 1976), movement precision (Fitts & Peterson, 1964; Glencross, 1976; Klapp, 1975), average velocity (Carlton, Robertson, Carlton & Newell, 1985; Falkenberg & Newell, 1980), and force production (Carlton, Carlton & Newell, 1987). This research suggests that the movement parameters influence RT by altering the programming requirements for the organization of the response.

Although RT is useful as an index of cognitive processing speed, MT appears to be relatively independent of cognitive task requirements. The overall MT measure is only minimally affected by task difficulty, and as such is appropriately used as a measure of the speed of movement within responses.

The separation of the traditional response time measure into RT and MT has been carried out infrequently in personality research (but see Barratt, 1967; Rammsayer, Netter & Vogel, 1993; Rammsayer, 1995; Stelmack, Houlihan & McGarry-Roberts, 1993). Most studies involving personality variables have used an undifferentiated response time measure. Some investigators using this undifferentiated measure have found that extraverts showed faster response times than introverts (Buckalew, 1973; Brebner & Flavel, 1978; Dickman & Meyer, 1988; Keuss & Orlebeke, 1977; Mangan & Farmer, 1967; Robinson & Zahn, 1988; Thackray, Jones & Touchstone, 1974; and

Zhorov & Yermolayeva-Tomina, 1972), while others reported no overall differences between groups (Brebner & Cooper, 1974; Casal, Caballo, Cueto & Cubos, 1990; Gupta & Nicholson, 1985; Hummel & Lester, 1977; Kirkcaldy, 1987). These disparities have been attributed to variations in experimental parameters, such that with stimuli that increase stimulus evaluation demands, faster response times are elicited in introverts than in extraverts, while conditions that increase response requirements elicit faster response times in extraverts than introverts (Brebner, 1990). Others have attributed the disparity to parameters such as interstimulus intervals, stimulus intensity, and time on task (Bullock & Gilliland, 1993; Robinson & Zahn, 1988). In general, however, no consistent association between extraversion and response time has been demonstrated. Whether the response time differences that have been reported are due to differences in reaction time, movement time, or both, remains unclear.

Cognitive psychophysiologists have often noted that RT and MT can be affected by a number of different processes, such as stimulus evaluation and response production. These measures might be useful in discriminating among proposed CNS bases for Extraversion. If individual differences in Extraversion are mediated by cognitive, cortical processes, these processes should exert their influence on the RT measure. On the other hand, if individual differences in Extraversion are mediated by peripheral nervous system processes, then differences in MT, rather than RT would be expected since MT measures motor speed relatively independently of stimulus analysis processes.

In the present study, two tasks were used to assess individual differences in RT and MT, i.e., a simple auditory reaction time task and a stimulus-response compatibility task. The simple reaction time task was chosen to minimize stimulus evaluation demands, and to allow for variations in motor execution requirements. Such requirements were manipulated by using three different distances between the target button and the home button. If differences between extraverts and introverts are determined by processes associated with ballistic movement, one would expect the differences in MT between groups to increase as the distance increased. The tones signalling responses were presented at two different intensities. It has been reported that higher intensities stimuli elicit faster response times than stimuli of lower intensity (Cattell, 1886; e.g. Jaskowski, Rybarczyk & Jaroszyk, 1994), but it is not known whether stimulus intensity affects MT. Further, stimuli of moderate intensity (85 dB) have been shown to be the most effective in eliciting differences between introverts and extraverts (Stelmack & Geen, 1992).

The stimulus-response compatibility task was chosen to explore the interaction of Extraversion with stimulus evaluation and response requirements. Response requirements were manipulated by introducing compatible and incompatible responses, while stimulus evaluation processes were manipulated by using congruent and incongruent stimulus arrays. Previous studies have shown that RTs to congruent stimuli are faster than to incongruent stimuli, but no interaction with personality has been studied. Similarly, RTs under compatible response conditions have been shown to be faster than under incompatible conditions, but again, no interaction with personality has been examined. If Extraversion is mediated by central response organizing processes, with extraverts "geared to respond" (Brebner, 1990), there should be interactions observed with the RT measure. Specifically, under incompatible response conditions, the RTs of extraverts should increase to a lesser degree than the RTs of ambiverts and introverts. However, if Extraversion is mediated by peripheral nervous system processes, little interaction with personality should be evident in RT, but substantial variation would be expected in MT, with extraverts exhibiting faster MTs than ambiverts and introverts under all conditions.

Method

Participants

Sixty-seven female university students volunteered their participation for the experimental session. The age of the participants ranged from 18 to 30 years (M=22, SD=3). The participants were selected on the basis of scores on the Extraversion scale of the Eysenck Personality Questionnaire - Revised (EPQ-R; Eysenck & Eysenck, 1991) to form 3 groups, with introverts scoring between 0-11, ambiverts between 13-17, and extraverts between 18-23. The intercorrelations between the personality scales of the EPQ-R are reported in Table 1, and the mean scores of the Extraversion groups on the EPQ-R scales are reported in Table 2.

Table 1. Intercorrelations of personality scales for the sample (N=67).

	Extraversion	Neuroticism	Psychoticism	Lie
E	-----			
N	-.22 *	-----		
P	-.12	.21 *	-----	
L	-.21 *	-.23 *	-.26 **	-----

* P<.05, **P<.01

Table 2. Mean scores (and standard deviations) on the personality scales for the groups participating in the experiments.

	Extraversion	Neuroticism	Psychoticism	Lie
Extraverts	20.4 (1.2)	11.7 (5.2)	5.9 (4.0)	6.5 (4.2)
Ambiverts	15.4 (1.6)	10.7 (3.3)	5.1 (3.3)	7.7 (4.1)
Introverts	6.0 (2.7)	14.6 (5.2)	6.3 (4.6)	8.7 (4.6)

There were no significant differences in age or personality score distribution between the samples for each task. Of the 67 participants, 50 completed both the simple reaction time task and stimulus-response compatibility tasks. Seven participants took part only in the simple reaction time task (N=57) and 10 others only in 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. Because correlations between RT and measures of mental ability have been reported, participants were also asked to report their grade point average, or, in the case of first year students, their average grade to date.

Apparatus

A response box was constructed with a home button, and target 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 target button. In the simple reaction time task, three blocks of stimuli were presented, each requiring the use of a different target button located at either 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 two target buttons, each 7 cm to the left and right of the home button. Templates were used to reveal only the buttons used in that block of trials and mask the unused buttons. The same finger that was kept on the home button was used for responding.

Procedure

Participants were seated 0.5 metres 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 signalled by the presentation of target tones, having a duration of 105 ms and a rise and fall time of 5 ms, 500 Hz, and 70 and 85 dB SPL. The intertrial interval, from the onset of one trial to the onset of the subsequent trial, was 3000 ms. Three blocks of 120 trials were presented, with intensities presented in random order with equal probability. The response button was located either 7, 15, or 23 cm from the home button. The order in which the distances were presented was counterbalanced across participants.

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, i.e., 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 were to respond by pressing a target button located in the same direction as the middle arrow pointed (compatible response). If the cue word was "OPPOSITE", participants were to respond by pressing the target button located in the direction opposite that of the middle arrow (incompatible response). Thus, there were four conditions, congruent stimuli with 1) compatible and 2) incompatible instructions, and incongruent stimuli with 3) compatible and 4) 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 sec later resulting in a trial to trial interval of 2400 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 two to five minutes 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.

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 RT and MT calculations.

Statistical Analysis

For the simple reaction time task, RT, MT, and accuracy data were analysed using a three-way ANOVA, with group (extravert, ambivert, introvert) as a between subjects factor and repeated measures on distance (7, 15, and 23 cm) and intensity (70, 85 dB SPL) factors. The effects of the order in which the target distances were presented were analysed in an additional three-way ANOVA, with Order as the between subjects factor, and repeated measure factors on distance (7, 15, and 23 cm) and intensity (70, 85 dB SPL) factors. Although the Greenhouse-Geisser procedure for adjusting confidence levels with repeated measures was used, no changes resulted.

For the stimulus-response compatibility task, RT, MT, and accuracy data were analysed with a three-way ANOVA, with group (extravert, ambivert, introvert) as a between subjects factor and repeated measures on stimulus congruency (congruent, incongruent) and response compatibility (compatible, incompatible) factors.

All post hoc analyses were conducted using Tukey's Honest Significant Difference test.

Pearson correlations were also calculated between personality scores and the dependent variables for each condition.

Results

Simple Reaction Time Task

There were no significant main effects or interactions related to the order in which the target distances were used for either RT (F<1) or MT (F<1).

Reaction Time

Consistent with previous literature, RTs to the 85 dB stimuli (279 ms) were significantly faster than to the 70 dB signal stimuli (291 ms), F(1,54)=52.11, P<.001. There were no significant differences in RT between the Extraversion groups (F<1), nor among the three response button distances, F(2,108)=2.63, P<.08. Interactions between group and distance, group and stimulus intensity, and distance and stimulus intensity were all nonsignificant (F<1). The interaction between group, distance, and stimulus intensity was also nonsignificant, F(4,108)=1.54, P=.20.

Movement Time

As expected, there was a main effect of distance on MT measures, F(2,108)=253.8, P<.001. MT increased substantially with increased distance to the response button, from 165 ms for the 7 cm distance, to 232 ms for 15 cm, and 273 ms for 23 cm. Differences in stimulus intensity did not elicit differences in MTs (F<1). There was a significant main effect of group on MT, F(2,54)=4.70, P<.013. Values for introverts were significantly slower than those for ambiverts and extraverts across all conditions (see Figure 1). Ambiverts and extraverts did not differ significantly from each

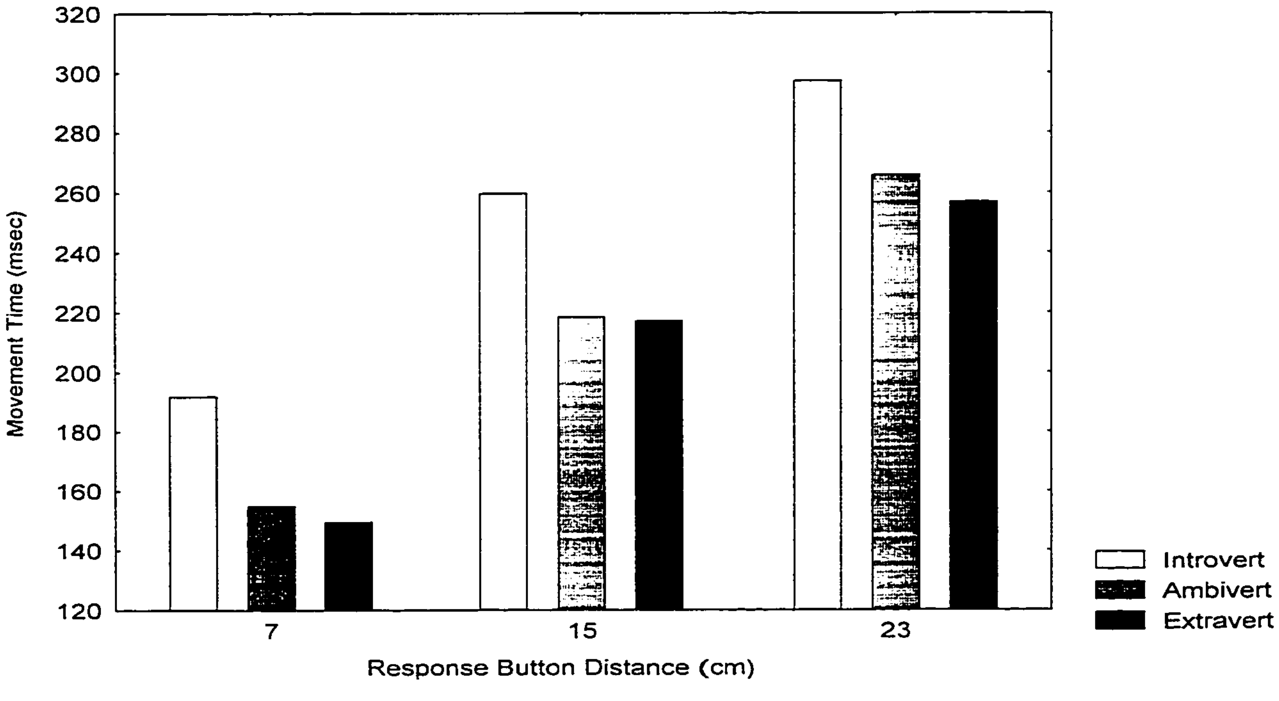

Figure 1. Movement times of the three extraversion groups on the simple reaction time task. Introverts showed significantly slower movement times than ambiverts and extraverts when the response button was 7 cm, 15 cm, and 23 cm from the home button.

other on this measure. It is important to note that the magnitude of the difference in MT between the Extraversion groups was constant across the three response button distances, i.e., extraverts moved between 40 and 46 ms faster than introverts in each of the target button distances. This finding implies that the process contributing to the difference in MTs between extraverts and introverts has its influence at the initial phase of the movement time component.

All two-way interactions and the three-way interaction were nonsignificant ($F \leq 1$).

Due to the significant correlation between Extraversion and Neuroticism (see Table 1), partial correlations were calculated. When controlling for Neuroticism, correlations between Extraversion and MT remained significant (see Table 3). However, when controlling for Extraversion, correlations between Neuroticism and MT dropped below significance levels, ranging from r=.01 (P=.31) to r=.20 (P=.07). This indicates that the differences in MT between Extraversion groups are not due to Neuroticism.

Table 3. Partial correlations between personality scores and movement time on the Simple Reaction Time task when controlling for Neuroticism.

	Extraversion	Psychoticism	Lie
MT 7cm	-.41 ***	-.07	-.05
MT 15cm	-.32 **	.13	-.06
MT 23cm	-.31 **	.15	-.01

** P<.01, ***P<.001 (one-tailed test)

RT and MT were positively correlated (*r*=.51, P<.001) as were RT and MT standard deviations (*r*=.56, P=.001). These correlations indicate that when cognitive demands are minimal, as in a simple reaction time task, RT and MT are affected by a common underlying factor, a finding in agreement with past research (Jensen, 1982). These factors might include the MT parameters of velocity and force production (Carlton et al., 1987).

Accuracy and Errors

Because extraverts are thought to select response strategies favouring speed, while introverts select strategies favouring accuracy (Frith, 1971), accuracy and error rates were also analysed. The analysis included several measures 1) the number of correct responses, 2) the number of anticipatory errors (fast responses), i.e., responses occurring prior to, and within 100 ms of stimulus onset, and 3) omission errors, in which the participant failed to respond. Another type of error is errors of commission, occurring when the participant missed the target button or hit the wrong button. These latter errors comprised .01% of the responses, and were not analysed.

Accuracy rates reflected differences relating to task manipulations. Accuracy decreased as the target distance from the home button increased, F(2,106)=6.01, P<.003, indicating that the further distances were more difficult to reach accurately. Accuracy also decreased as the stimulus intensity increased, F(1,53)=4.78, P<.03. There were no group differences (F<1). Introverts did not appear to select an accuracy strategy over speed, nor did extraverts sacrifice accuracy for speed in this task. All two-way and three way interactions were nonsignificant (F≤1).

Errors categorized as omissions did not reveal any significant effects for group (F<1), target distance, F(2,106)=1.03, P<.36, or intensity (F<1). All interactions were nonsignificant (F<1).

There were more fast response errors made with the 15 cm and 23 cm distances than with the

7 cm distance, F(2,108)=5.70, P<.004, perhaps these were made in an attempt to compensate for the further distance to be travelled. There were also more fast response errors to the 85 dB stimuli than to the 70 dB stimuli, F(1,54)=4.09, P<.05. There were no group differences (F<1). All interactions were nonsignificant (F<1).

Correlational analysis revealed that RT was correlated with fast response errors in the 7 cm and 15 cm conditions, ranging from *r*=-.26 (P=.05) to *r*=-.37 (P=.004). Because fast response errors are not included in the RT data, this correlation indicates that the participants who tended to make fast response errors also had faster legitimate RTs.

Stimulus-Response Compatibility task

Reaction Time

RTs to congruent stimuli were faster (509 ms) than to incongruent stimuli (574 ms), F(1,57)=174.04, P<.0001. RTs under compatible response instructions were faster (527 ms) than under incompatible response instructions (556 ms), F(1,57)=43.17, P<.0001. There was also a significant interaction between congruency and compatibility, F(1,57)=21.17, P<.001). Compatible responses were faster than incompatible responses, especially when stimuli were congruent. Although there was no main effect of group (F<1), there was a three-way interaction between group, congruency and compatibility (see Figure 2). The RTs of extraverts were faster than those of introverts and ambiverts in the incompatible congruent condition, F(2,57)=4.30, P<.018 (means were 510 ms, 536 ms, and 543 ms for extraverts, ambiverts, and introverts, respectively). There were no significant differences in the other conditions. This indicates that extraverts respond to the demands of response incompatibility faster than introverts or ambiverts.

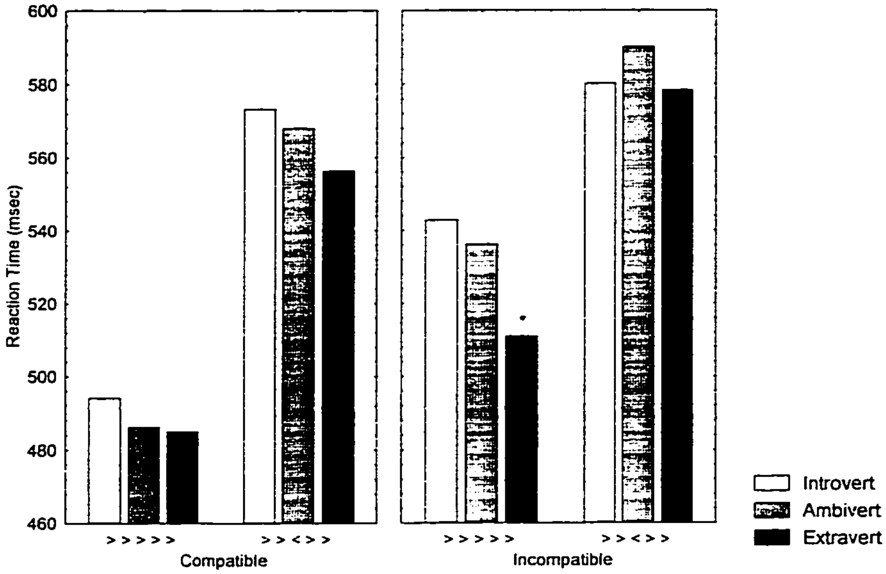

Figure 2. Reaction times of the three extraversion groups on the stimulus-response compatibility task. The RT of extraverts was significantly faster than that of introverts and ambiverts in the incompatible-congruent condition, as indicated by a " * ".

Correlations between RT and MT (ranging from $r=.18$ to $r=-.10$) were not significant. This result contrasts with the significant RT-MT correlations in the simple reaction time task, indicating that although RT and MT share an underlying common factor, there are also processes which affect these measures independently. Perhaps this only becomes evident when the cognitive demands or the response production demands are increased. Nevertheless, it is clear that although the two measures are related, there is some justification for considering RT and MT independently.

Movement Time

There was a main effect of stimulus congruency, with MTs in the congruent stimulus conditions approximately 9 ms faster than in the incongruent stimulus conditions (163 ms vs 172 ms), $F(1,57)=20.72$, $P<.001$. Although the magnitude of the difference is small, it replicates an effect reported in the literature (Houlihan et al., 1994). The flanking arrows in an incongruent array may exert an inhibition over responses and affect MT in the same way as it does RT. This inhibition appears to operate even after the response process has been initiated, and thus affects MT. An alternative explanation is that there may be additional processing of the stimulus, which continues even while the response is in progress. Response compatibility had no main effect on MT, F(1,57)=1.16, P<.29. Response compatibility interacted with congruency, F(1,57)=5.27, P<.03; the movement times of incompatible-incongruent responses were 4 ms faster movement times than the compatible-incongruent responses.

Across all conditions, the MTs of extraverts were faster than those of introverts, F(2,57)=4.14, P<.02 (see Figure 3). Post hoc analyses showed that in each condition, the MTs of the extraverts were faster than those of either ambiverts or introverts, and further, that the MTs of the

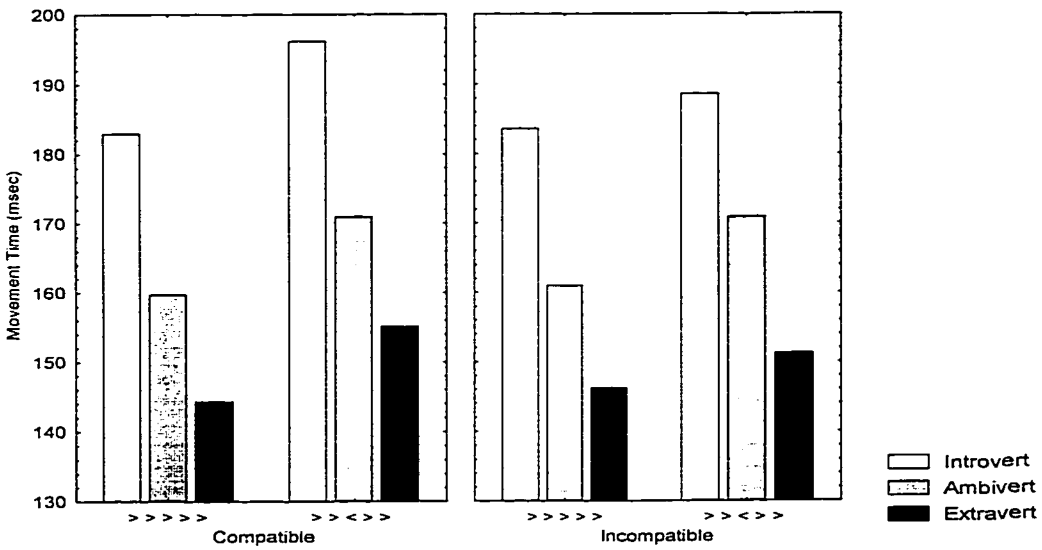

Figure 3. Movement times of the three extraversion groups on the stimulus-response compatibility task. Extraverts had faster movement times than ambiverts, and ambiverts had faster movement times than introverts in each condition.

ambiverts were faster than those of the introverts. Extraverts were consistently 38 to 42 ms faster than introverts. This narrow range of difference argues that the variation in MT attributable to Extraversion remains constant across differences in task difficulty.

Again, because of the significant correlation between Extraversion and Neuroticism, partial correlations were calculated. When controlling for Neuroticism, correlations between Extraversion and MT were significant, ranging from *r*=-.30 (P=.01) to *r*=-.40 (P=.001) (see Table 4). However, when controlling for Extraversion, correlations between Neuroticism and MT dropped below significance levels, ranging from *r*=.12 (P=.17) to *r*=.18 (P=.08). It is again evident that differences in MT are largely attributable to Extraversion.

Table 4. Correlations between movement time and personality scores on the Stimulus-Response Compatibility task when controlling for Neuroticism.

	Extraversion	Psychoticism	Lie
MT CC	-.40 ***	-.01	-.16
MT CI	-.33 **	-.08	-.12
MT IC	-.39 ***	-.09	-.11
MT II	-.30 **	-.11	-.17

<u>Note</u>: CC = compatible, congruent; IC = Incompatible, congruent;

CI = compatible, incongruent; II = Incompatible, incongruent

**P<.01 ***P<.001 (one-tailed test).

Accuracy and Errors

Analyses of accuracy and errors for the Stimulus-Response Compatibility task proceeded along the same lines as the simple reaction time task. Accuracy rates reflected differences due to task manipulations. The presentation of congruent stimuli resulted in more accurate responses than incongruent stimuli, F(1,57)=24.61, P<.001, and compatible response instructions resulted in higher levels of accuracy than did incompatible response instructions, F(1,57)=13.11, P<.001, but there was no effect of group (F<1).

There were no significant differences in regards to fast responses errors and effects for group (F<1), congruency (F<1), or compatibility (F<1).

The analysis of omission errors revealed main effects of task, with congruent stimuli eliciting less of this error than incongruent stimuli, F(1,57)=19.88, P<.001, and compatible instructions eliciting less than the incompatible instructions, F(1,57)=6.53, P<.01. Although there was no main effect of group, F(2,57)=1.95, P<.15, there was an interaction between group and congruency, F(2,57)=3.13, P<.05. Post hoc analysis revealed that introverts withheld their responses significantly more often than extraverts in all conditions except the compatible-congruent condition.

Correlational analysis revealed that RT was correlated with accuracy, such that as accuracy increased, RT was faster. Correlations ranged from *r*=-.38 (P=.003) to *r*=.56 (P=.001). This suggests that participants who tended to respond accurately also tended to respond faster.

Both RT and MT were correlated with omission errors, such that as the number errors increased, RT and MT slowed. Correlations ranged from *r*=.49 (P=.001) to *r*=.67 (P=.001) for the RT data, and from *r*=.37 (P=.004) to *r*=.45 (P=.001) for the MT data. This indicates that participants who tended to withhold responses also tended to have slower RTs and MTs.

Significant correlations also emerged between extraversion and omission errors in the incompatible response conditions, such that participants tending toward introversion also tended to withhold incompatible responses. Correlations were *r*=-.25 (P=.05) for the incompatible-congruent condition, and *r*=-.29 (P=.03) for the incompatible-incongruent condition.

Discussion

The most salient result to emerge from the data was that extraverts exhibited faster movement times than introverts. This difference was apparent in both the simple reaction time task and the stimulus-response compatibility task. The simple reaction time task addressed the issue of whether the faster response times of extraverts which have been reported in the literature were due to the RT or the MT component. In the present study, it is clear that MT, not RT, differentiates introverts from extraverts. This effect endorses other studies that measured MT and personality (Barratt, 1967; Rammsayer et al., 1993; Rammsayer, 1995; Stelmack et al., 1993).

The fact that RT showed no overall correlation with Extraversion suggests that Extraversion is not related to either stimulus evaluation or response selection processes. Instead, as indicated above, Extraversion-Introversion differences are associated with motor processes that occur after RT. If the ballistic requirements of the simple reaction time task influenced the differences in MT between introverts and extraverts, the magnitude of the differences between groups would increase as the distance increased. Instead, it was observed that the magnitude of the differences remained constant. This means that the difference between introverts and extraverts is present within the first 7 cm (the shortest distance). In a previous study (Stelmack et al., 1993), a correlation of -.39 was observed between Extraversion and MT, even though the subjects moved only two centimetres on a computer mouse. Thus, it is the early phase of MT, rather than the later ballistic phase, that is associated with differences in Extraversion. It is likely that introverts and extraverts have equal average velocities, or equal peak velocities, but extraverts accelerate to that velocity faster than introverts.

The task manipulations elicited anticipated differences. In the simple reaction time task, responses were initiated faster to 85 dB tones than to 70 dB tones, following reports in the literature (Cattell, 1886; Jaskowski et al., 1994). In the stimulus-response compatibility paradigm, all groups responded slower to incongruent than to congruent stimuli, and incompatible response instructions elicited slower RTs than compatible response instructions. These findings were also expected based on past research (Crossman, 1955; Fitts & Deininger, 1954).

The stimulus-response compatibility results on the RT data showed a significant group by stimulus congruency by response compatibility interaction. These results follow the same pattern as those found by Bashore (1990) using an undifferentiated response time measure. Although Bashore did not report any statistical analysis, he described the effect in terms of the “cost” of incompatibility. When congruent stimuli are compared under compatible and incompatible response instructions, a significant increase in RT is observed in the incompatible response condition. Similarly, when incongruent stimuli are compared under compatible and incompatible response instructions, an increase in RT is again observed, although this time to a lesser, even nonsignificant degree. Bashore referred to this pattern as the reduced cost of incompatibility when an incongruent array was presented. He suggested that when an incongruent array was presented, the flanking arrows in that array may actually facilitate a response away from the direction the middle arrow pointed; in effect, the incongruent array facilitated the incompatible response. This explanation appears plausible and supported by the present study.

The effect of congruent stimuli eliciting faster MTs than incongruent stimuli is a replication of the effect obtained by Houlihan et al. (1994). Although the MTs elicited by congruent and incongruent stimuli differ by only 9 ms, the consistent pattern of the results, both within and between experiments, suggests that MT is at least minimally affected by ongoing stimulus evaluation within the MT phase. Although MT is affected to a small extent by stimulus congruency, it is affected more extensively by personality factors.

One possible contributor to the MT differences may have been motivation. It is well recognized that introverts tend to self select strategies that match position (accuracy strategy), while extraverts tend to adopt strategies that match velocity (speed strategy) (Frith, 1971). It is possible that despite the instructions to move as quickly as possible, the introverts simply did not move as fast as they could have. Extraverts often commented that since they found the task boring, they imagined that it was a competitive game of some sort. However, if lack of motivation played a part in the results, it should have been observable in both the RT and MT data. The lack of differences in the RT data argues against such motivational effects. Any lack of motivation should also have resulted in a stronger negative correlation as distance to the target increased, rather than the weaker correlation that was observed.

It is clear that research involving response time measures needs to differentiate RT and MT. While the field of intelligence has recognized this need, and often considered MT a mere nuisance variable, in personality research it is evidently vital. Further research using subcomponents of the MT process is warranted to determine whether the differences are due to the acceleration to peak velocity, as suggested by this study, or to other movement parameters. Another possible area for differences would be in the approach to the target. It is known that introverts self-select accuracy over speeded strategies (Frith, 1971). Although no differences were observed with regard to strategy and extraversion in this study, there may still be differences in the speed of approach, or the distance at which the slowing phase begins.

The faster MTs shown by extraverts complement the reports of behavioural differences observed between extraverts and introverts, with extraverts moving more frequently (Gale, 1969; Hocking & Robertson, 1969; Howarth, 1964), and more extensively (Taft, 1967; Wallach & Gahm, 1960) than introverts. A related area of research is the biochemical bases of the differences in motor processes. The stimulus-response compatibility task is particularly useful in that it comprises a paradigm adaptable to the exploration of the biochemical bases. Studies that manipulate neurotransmitters, for example, AMPT modulation of dopamine (Rammsayer et al., 1993), could use such a task to separately analyse the neurochemical influence on stimulus evaluation and response related processes. From any perspective, MT provides important information regarding processes underlying Extraversion differentiation.

End of chapter 1.

Chapter 2

The Effect of Response Execution on P3 Latency, Reaction Time and Movement Time

Abstract

This study examined the effect of response selection and execution on P3 latency during the performance of simple reaction time and stimulus-response compatibility tasks. Response time on these tasks was defined in terms of reaction time (RT) and movement time (MT). Event-related brain potentials were recorded from 67 female participants concurrently with the performance measures. On the simple reaction time task, the distance of the response button from the home button was varied (7, 15, and 23 cm). When stimulus evaluation demands are minimal, response execution does affect P3 latency, with increased response button distance resulting in increased P3 latency. However, these movement effects are quite modest, and in most protocols, will 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, while RT and P3 amplitude were affected by response compatibility.

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 employed in this work, however, there was no clear distinction 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 paper, 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 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, it is often only response time 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 effect on P3 latency (Kutas et al., 1977). Similar effects were observed on a Stroop task, where 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 analysing the chronometry of mental ability, it is now common practice to distinguish response time in terms of reaction time (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, while 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, while MT is not, it is thought that RT is primarily determined by cognitive processing factors, and that MT reflects the speed of sensori-motor 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 increases with increases in response processing demands, but MT does not. This result is found in studies that used stimulus-response compatibility paradigms (Frowein, 1981; Houlihan, Campbell & Stelmack, 1994; Simon, 1969), as well as studies that varied the number of response alternatives (Brainard, Irby, 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 response only demanded the depression of a response button, but there was no ballistic movement required. The structure of the tasks employed also are 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 small 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 reaction time, 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 mouse as a home button. Although this 2 cm distance is 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 reaction time task, and by exploring the interactive influence of stimulus congruence and response compatibility. In the simple reaction time task, movement time was varied by using blocks of trials that required traversing different distances to reach the response button. Stimuli were auditory tones that occurred every three seconds. Because stimuli of higher intensity are known to elicit faster response times (Cattell, 1886; e.g. Jaskwoski, Rybarczyk, & Jaroszyk, 1994), but it is not known whether the effect is at the level of RT, 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 reaction time. 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, where 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 are presented to the left ear, response times are delayed compared to 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 Massioui, 1995; Ragot, 1984; Ragot & Lesèrve, 1986; Ragot & Renault, 1981; Renault, Fiori & Giami, 1988; Sommer, Leuthold & Hermanutz, 1993; Valle-Inclán, 1996a, 1996b). A few studies have found no effects (Fiori, Ragot & Renault, 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 is delayed by response incompatibility (Christensen, Ford & Pfefferbaum, 1996, Pfefferbaum, Christensen, Ford & Kopell, 1986), though the result is not consistent (Houlihan, Campbell & Stelmack, 1994; Pfefferbaum, Christensen, Ford & Kopell, 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.

Method

Participants

Sixty-seven female university students volunteered their participation for the experimental sessions. The age of the participants ranged from 18 to 30 years (M=22, SD=3). Of the 67 participants, 50 completed both the simple reaction time and stimulus-response compatibility tasks. Seven participants took part only in the simple reaction time task (N=57) and 10 others only in 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 reaction time 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 mask the unused buttons. The same finger that was kept on the home button was used for responding.

Procedure

Participants were seated 0.5 metres 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 signalled 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 3000 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 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, i.e., 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, it was a 2 x 2 factorial design, including congruent arrays with 1) compatible and 2) incompatible instructions, and incongruent arrays with 3) compatible and 4) 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 sec later resulting in a trial to trial interval of 2400 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 two to five minutes 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.

EEG Recordings

The electroencephalogram (EEG) was recorded from Ag/AgCl electrodes affixed to the midline frontal (Fz), central (Cz) and parietal (Pz) scalp sites. The horizontal electrooculogram (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 infra-orbital ridges of the left eye. The reference electrode was on the left mastoid. Interelectrode impedances were below 2 kOhms. The high filter was set at 30 Hz, and the time constant at two seconds. The EEG and EOG were sampled at 512 Hz and stored continuously to hard disk. All recordings were performed with InstEP™ software. 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 FFT algorithm. Single trials were reconstructed beginning 100 ms prior to stimulus onset and continuing for 1000 ms following it. 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 prior to 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.[1]

Results

Simple Reaction Time Task

The objective of this simple reaction time 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 in order to complete the response. The impact of response button distance on P3 latency and amplitude was evaluated.

Data Analysis

For the simple reaction time task, RT, MT, and P3 data were analysed using a two-way 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 analysed in a three-way ANOVA, with Order as a between subjects factor, and repeated measures on distance

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[1] 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 (Callaway, Halliday, Naylor & Thouvenin, 1984). The reverse effect, however, where single-trial procedures yielded larger experimental effects than averaged data, has also been reported (Kutas et al., 1977; Leuthold & Sommer, 1998). Moreover, in comparison to averaged ERP procedures, single-trial procedures are much more sensitive to signal-to-noise ratio (cf. Fein & Turetsky, 1989; Gratton, Kramer, Coles & Donchin, 1989; Möcks, Köhler, Gasser & Pham, 1988). This may be one reason why the mean 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). Heeding this caveat is especially important with small P3 amplitudes, as is the case in the simple reaction time tasks of this study. The issue of averaged versus single-trial procedures has recently been reviewed (Verleger, 1997) with the conclusion that the few studies available find that experimental effects were similar using both procedures.

(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 was 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 reaction time 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, ϵ=.57, but the button press conditions did not differ amongst themselves. This effect has been attributed to the additional motor programming required to accurately press a button (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)=70.36, 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 (96%, 97%, and 98% 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/sec) also increased as response button distance increased, from 42 cm/sec at 7 cm, to 65 cm/sec at 15 cm, to 84 cm/sec at 23 cm. This establishes 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).

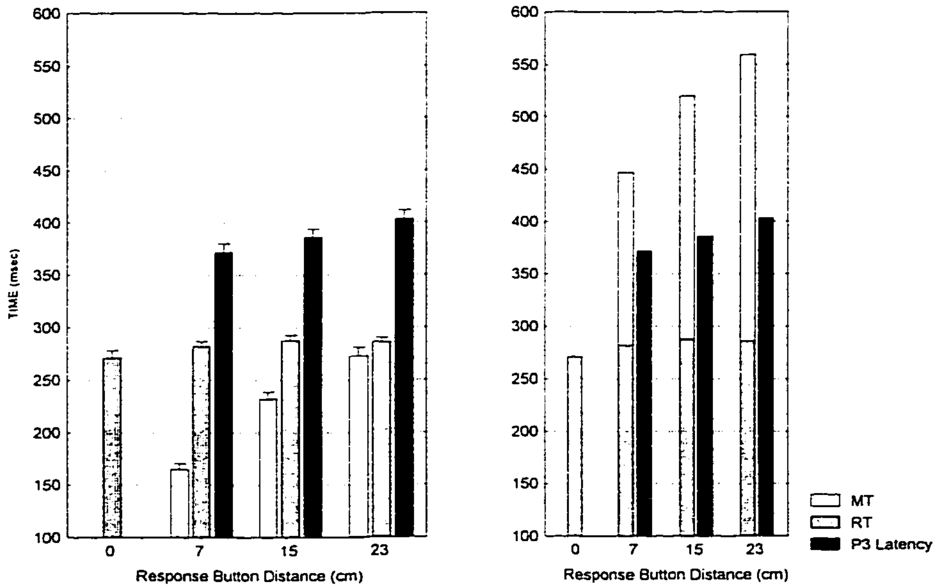

Figure 1 (A and B). Means and standard errors for P3 latency, RT and MT on the simple reaction time task. Figure 1A plots MT as an absolute value. Figure 1B plots MT with RT as its zero point. RTs to the simple lift-off are faster than the button presses, but otherwise are not significantly different from each other. All MTs are significantly different from each other. P3 latencies are faster in the 7 cm and 15 cm than in the 23 cm condition.

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 consistently visible 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 ms vs 396 ms), $F(1,56)=28.85$, $P<.0001$. Similar intensity effects were previously observed between stimulus intensity and P3 latency (Papanicolaou, Loring, Raz & Eisenberg, 1985; Sugg & Polich, 1995).

P3 latency was also influenced by response button distance, $F(2,112)=10.54$, $P<.00007$, $\epsilon=.84$. 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 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 reaction time paradigms that measured RT as lift-off time (McGarry-Roberts et al., 1992; Ritter, Simson & Vaughan, 1972). It is notable that 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, $F(2,112)=2.84$, $P<.06$, $\epsilon=.86$. 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 averages 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. It may be that this effect only emerges 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. The outcome of this second experiment is reported following the stimulus-response compatibility paradigm.

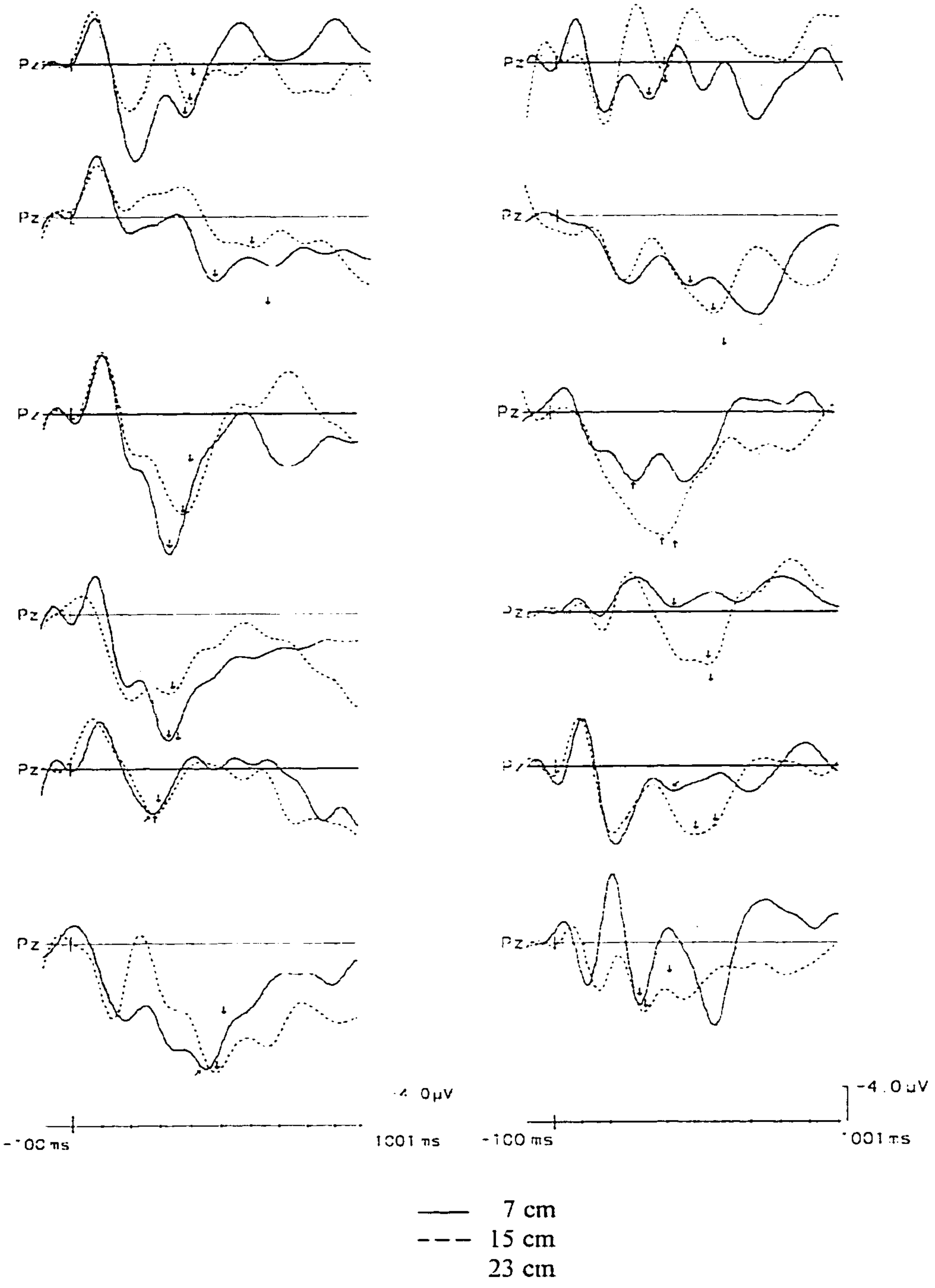

Figure 2. Waveforms from the simple reaction time task for twelve individuals. Waveforms show averages for each response button distance with the 85 dB stimuli. P3s are indicated by arrows.

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, i.e., 7 cm.

Data Analysis

For the stimulus-response compatibility task, RT, MT, and ERP data were analysed 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 responses 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.

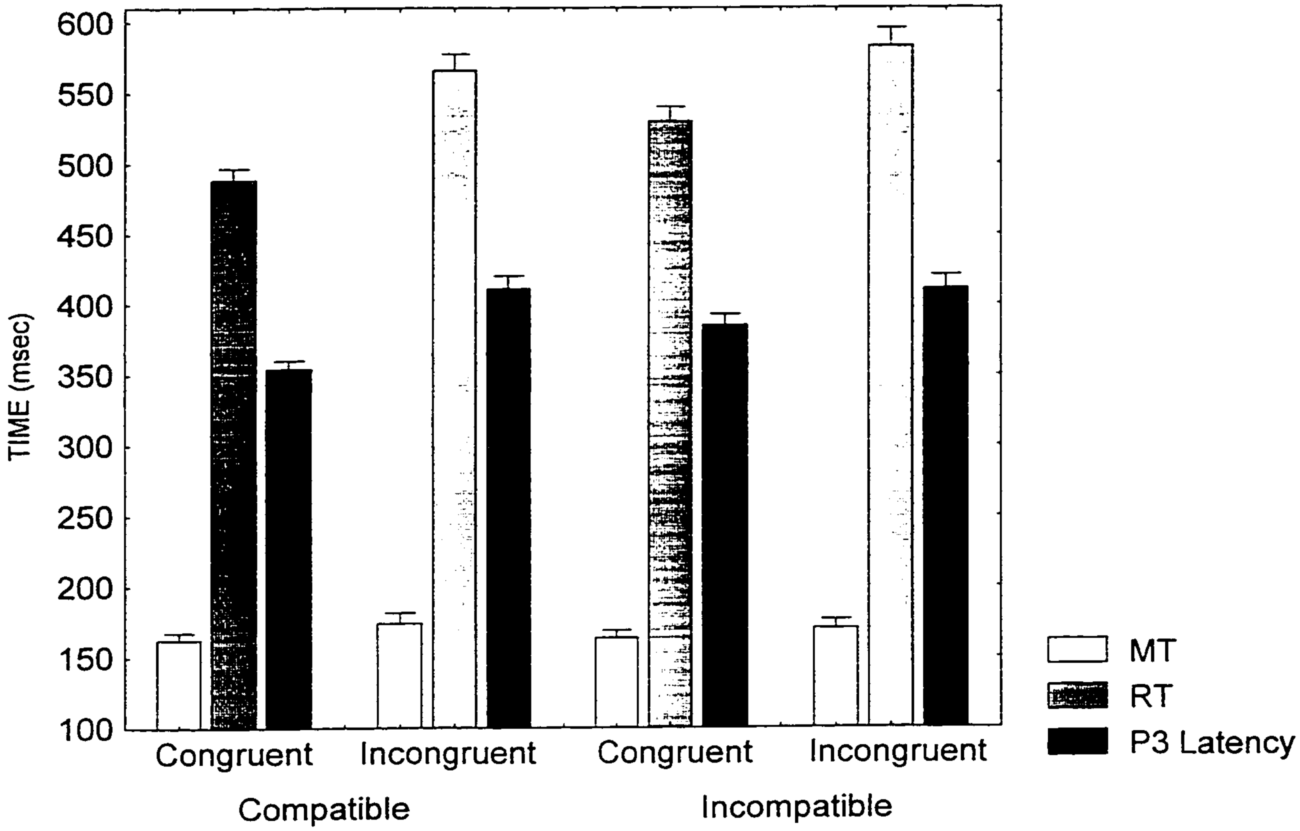

Figure 3. Means and standard errors for P3 latency, RT and MT on the stimulus-response compatibility task. RTs, MTs, and P3 latencies are faster for congruent than incongruent arrays. RTs are faster for compatible than incompatible response instructions.

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 behavioural 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, it 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 μv and 2.53μv, respectively), F(1,59)=23.18, P<.0001.

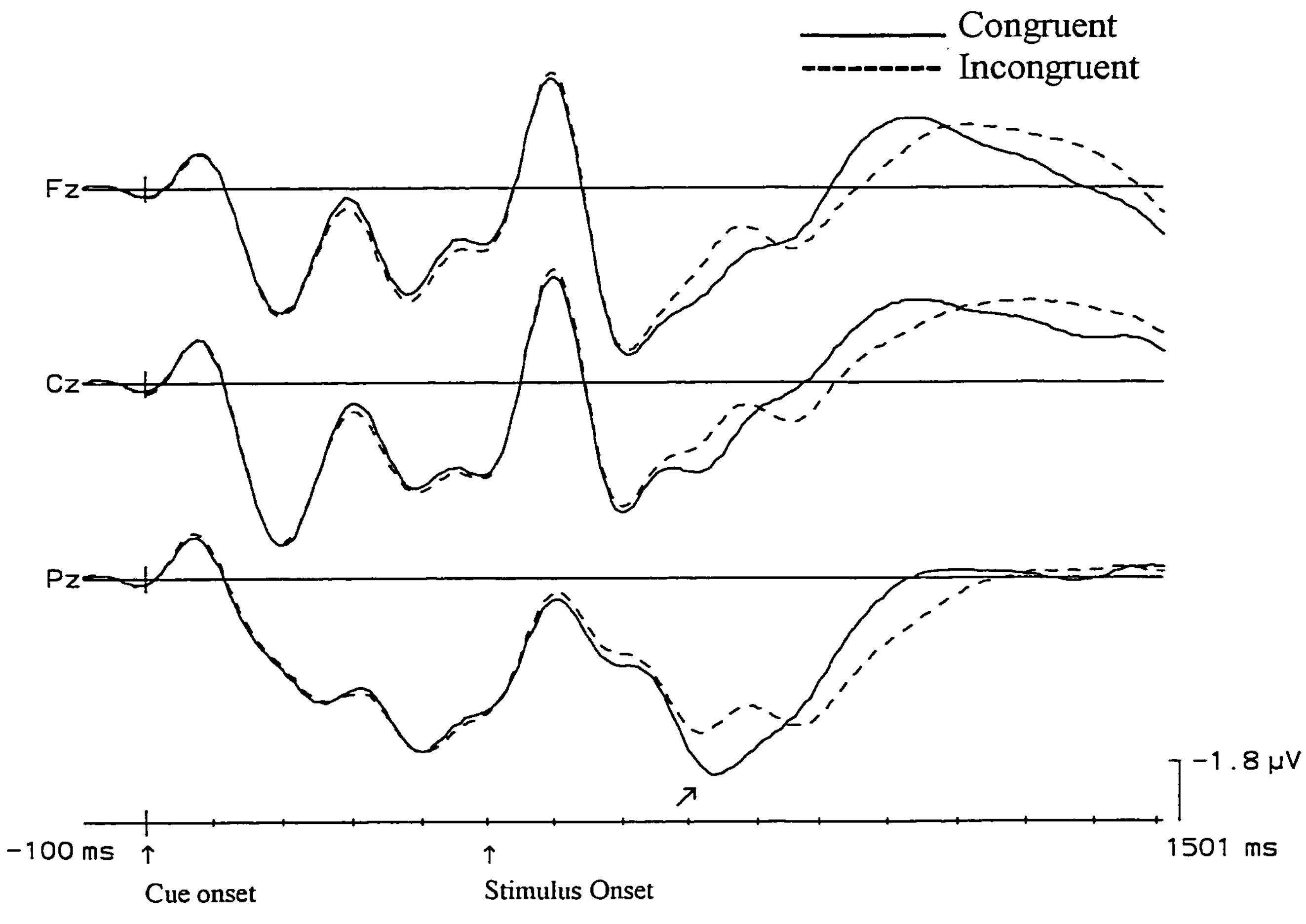

Figure 4. Grand average waveforms recorded at Fz, Cz, and Pz showing P3 latencies for congruent and incongruent arrays on the stimulus-response compatibility task. P3 is indicated by an arrow.

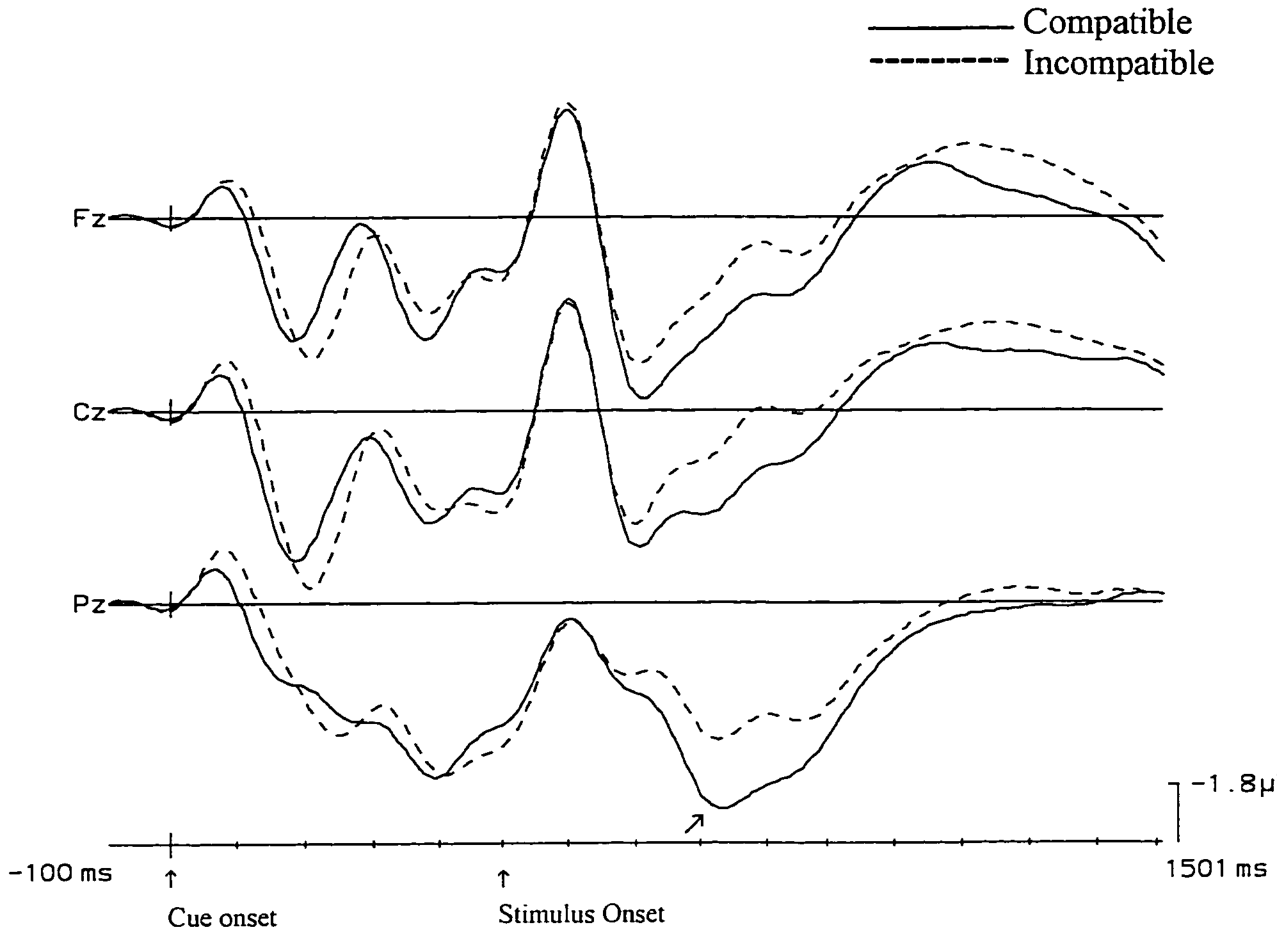

Figure 5. Grand average waveforms recorded at Fz, Cz, and Pz showing P3 amplitudes for compatible and incompatible response conditions on the stimulus-response compatibility task. P3 is indicated by an arrow.

Also, instructions for compatible responses elicited larger P3 amplitudes than did incompatible response instructions (means were 4.59μv and 1.67μv, 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.

Experiment 2

As previously noted, the response button distance effect was obscured in the grand average waveforms of the simple reaction time task. Also, it was clear that the response button distance effects were observed under conditions where stimulus evaluation demands were minimal. Another experiment was conducted using a standard oddball paradigm in order 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, SD=1.7). 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

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 3000 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. It should be noted that these instructions transform the task into a go/no-go task, rather than a simple reaction time 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 %), nor 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 $F(2,12)=3.47$, $P<.10$, $\epsilon=.61$. 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 measures, $F(2,12)=38.63$, $P<.00001$, $\epsilon=.96$. MT increased substantially with increased distance to the response button. An increase in velocity with increasing response button distance was observed,

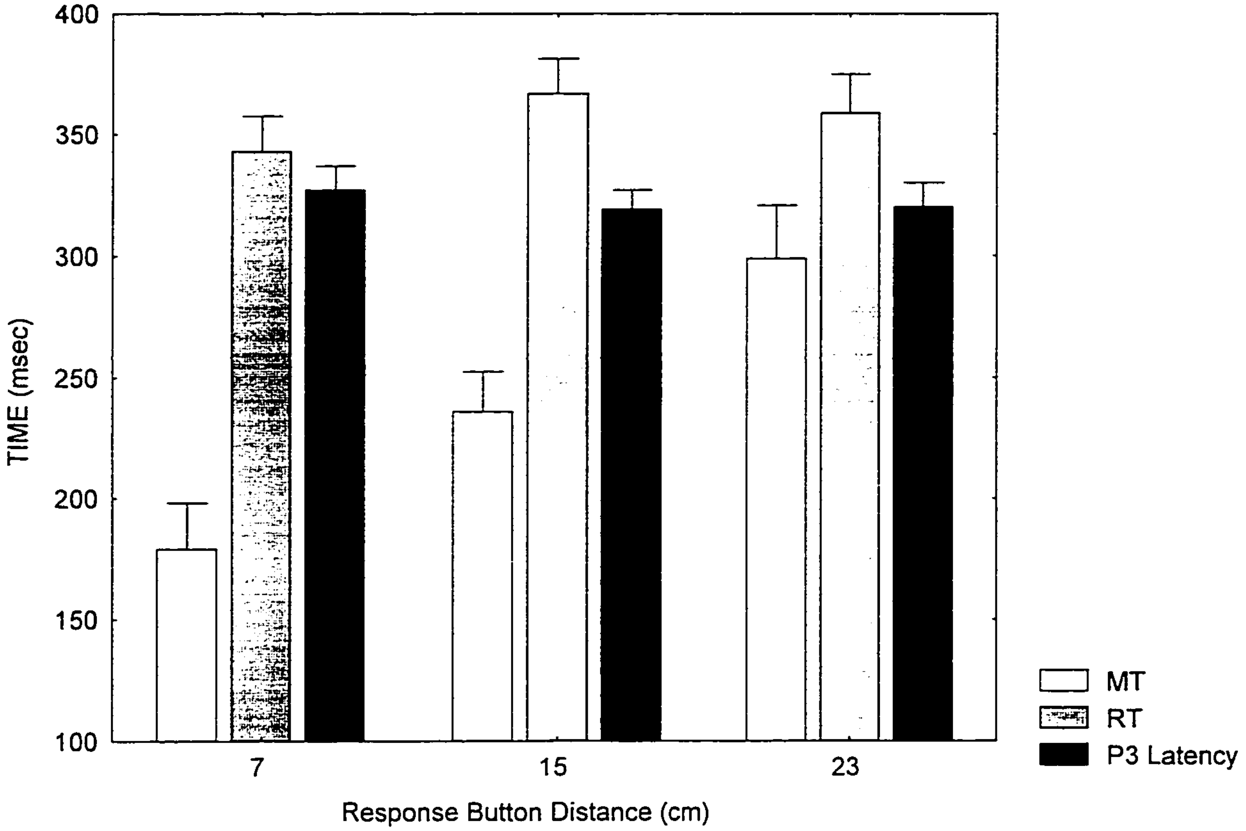

Figure 6. Means and standard errors for P3 latency, RT and MT on the oddball task when only rare tones are designated targets. Only MT increases with increasing response button distance.

as in experiment 1. The velocity of the movements were 39, 64, and 77 cm/sec at 7, 15, and 23 cm, respectively.

ERP Measures

Figure 7 presents grand average waveforms for the standard oddball task. There was no significant effect of response button distance on P3 latencies, F<1. Orthogonal trend analysis verified that the linear component of the distance effect was not significant, F<1. Further, there was no

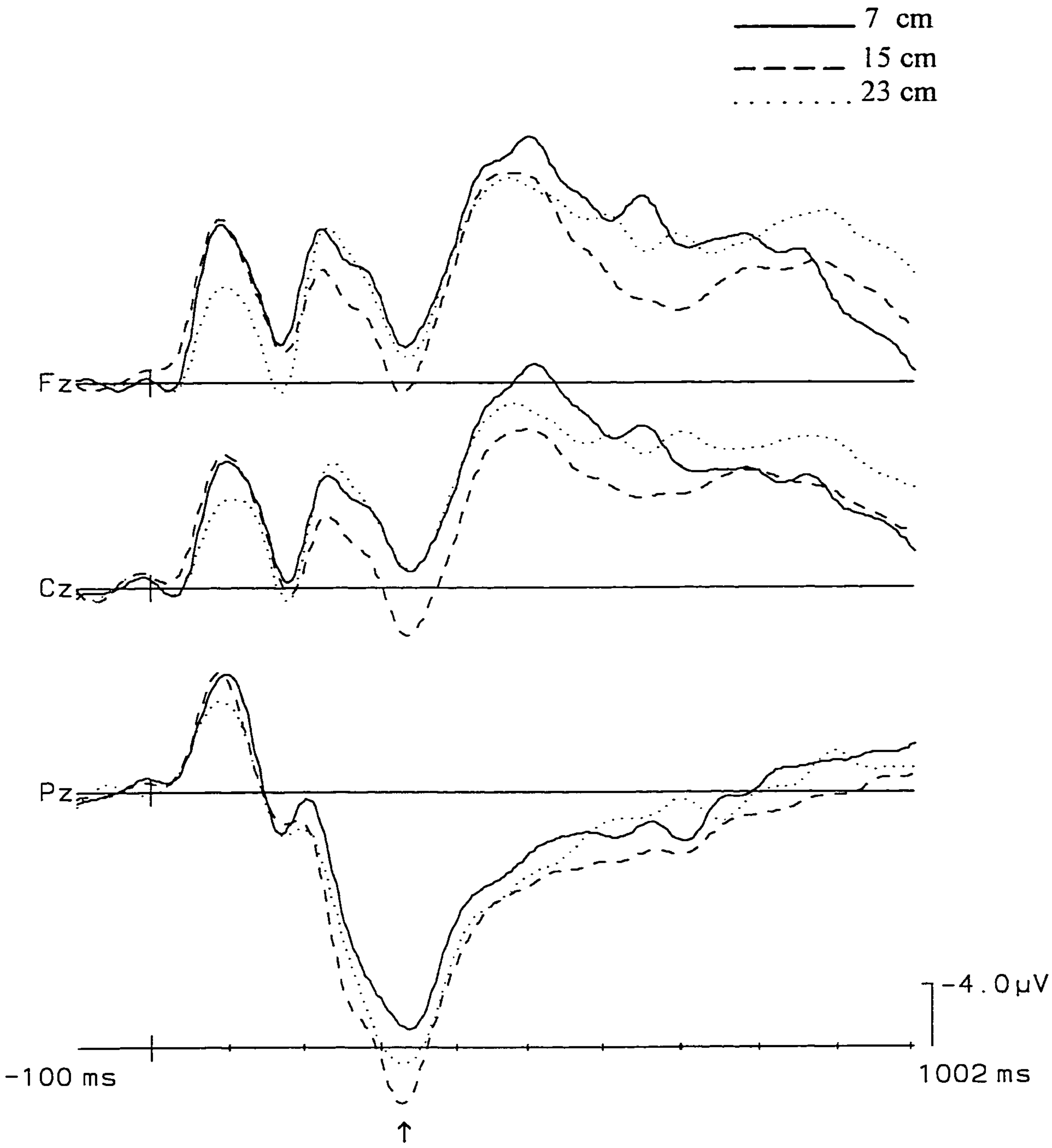

Figure 7. Grand average waveforms for rare stimuli on the oddball task when only rare tones are designated targets. P3 is indicated by an arrow.

significant effect of response button distance on P3 amplitudes, F(2,12)=3.61, P<.10, ϵ=.61. Orthogonal trend analysis concurred that the linear component was not significant, F(1,6)=1.14, P<.33.

These data indicate that when stimulus evaluation is required to the degree that targets must be discriminated from non-targets, P3 latency is unaffected by the demands of motor execution.

Experiment 3

The oddball task above was different from the simple reaction time 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 reaction time task had equiprobable stimuli. Also, the oddball task required participants to respond to only the rare tones, essentially being a go/no-go task, while the simple reaction time task required a response to each tone. In order 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, 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 are based on trials in which the rare stimuli were presented.

Results

Performance Measures

Figure 8 presents performance and P3 latency means from this task. There was no significant

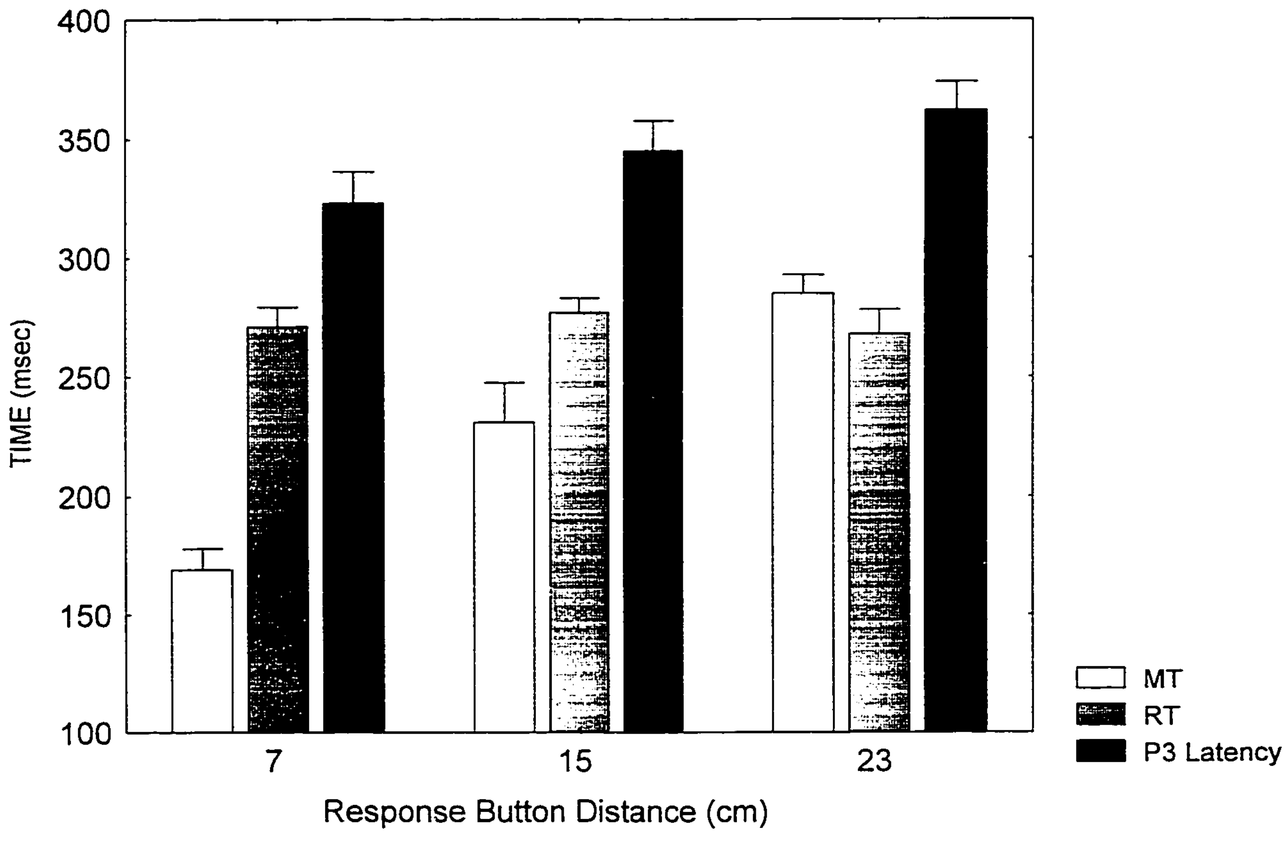

Figure 8. Means and standard errors for P3 latency, RT and MT on the oddball task when all tones are designated targets. Both P3 latency and MT increase with increasing response button distance.

main effect of response button distance on RTs (F<1). Orthogonal trend analysis verified 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, ϵ=.99. An increase in velocity was observed as in experiments 1 and 2. Velocity was 41, 65, and 81 cm/sec at 7, 15, and 23 cm, respectively.

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<.08.

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

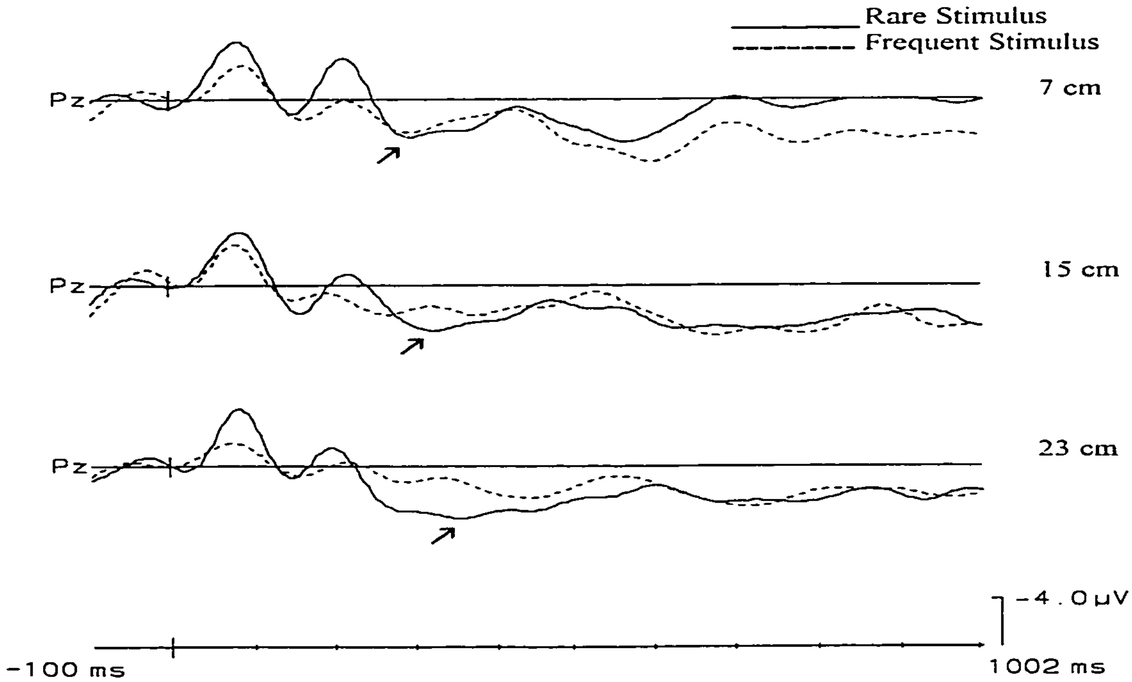

Figure 9. Grand average waveforms for rare and frequent stimuli on the oddball task when all tones are designated targets. P3 is indicated by an arrow.

response button distance on P3 latencies approached statistical significance, F(2,12)=3.62, P=.09, ϵ=.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 in order to determine their effect on P3 latency. To that end, a simple reaction time task was employed 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, reaction time (RT) and movement time (MT). RT was defined as the time from stimulus onset to the lift-off from a home button, while 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 reaction time paradigm, RT was noted to precede P3 latency. This has been observed whenever RT was measured as a lift-off in a simple reaction time 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 reaction time task tended to be somewhat smaller than those observed in a typical oddball task. The morphology of the waveform was quite 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 reaction time 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.

In order 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, i.e., when targets were to be discriminated from non-targets, the response execution effect on P3 latency was not maintained. However, when stimulus evaluation requirements were again reduced, i.e., 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.

In this simple reaction time 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 towards 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, there were consistent effects of stimulus congruency 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).

Congruent arrays elicited faster MTs than did incongruent arrays. This is a replication of the effect obtained by Houlihan et al. (1994). Although the MTs elicited by congruent and incongruent arrays differ 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, while 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 it. Specifically, McCarthy and Donchin (1981) and Magliero et al. (1984) used explicit instructions that preceded the target stimuli, and found that RT was affected much more than P3 latency. In contrast, Christensen 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 reaction time tasks, however, suggest that this conclusion should be tempered, as motor execution can influence P3 latency. This effect, however, is only observed when stimulus evaluation demands are minimal. Increasing stimulus evaluation demands even slightly, as in the typical oddball, 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 reaction time tasks merits some consideration. RT provides a discrete measure of cognitive processing activity that precedes motor execution. Combining these measures with P3 latency studies allows one to assess the independence of P3 from both response selection and response execution processes.

End of chapter 2.

Chapter 3

An Event-Related Potential Analysis of Extraversion and Individual Differences in Cognitive Processing Speed, Sensory Reactivity, and Response Execution

Abstract

Individual differences in cognitive processing speed, sensory reactivity, and response execution were examined in relation to extraversion. Event-related potentials (ERPs) were recorded concurrently with response time measures as participants (N=67) performed simple reaction time (SRT) and stimulus-response compatibility (S-RC) tasks. Response time was differentiated into reaction time (RT) and movement time (MT). On the SRT task, introverts displayed larger N1 amplitudes than extraverts to auditory tones, an effect that is consistent with the enhanced sensory reactivity of introverts to punctate physical stimuli. Evidence from the P3 latency measure, an index of cognitive processing speed, was equivocal. On the SRT task, there was no difference between groups. On the S-RC task, however, there were significant positive correlations between P3 latency and extraversion. As previously reported, extraverts displayed faster MTs than introverts on both the SRT task, where response button distance was varied, and on all conditions of the S-RC task. These effects are discussed in terms of the sensory and motor bases of extraversion.

An Event-Related Potential Analysis of Extraversion and Individual Differences in Cognitive Processing Speed, Sensory Reactivity, and Response Execution.

The extraversion trait is arguably the most intensively investigated trait in the domain of personality description. Moreover, there is a voluminous literature documenting the efforts to determine the causal bases of variation in the extraversion trait by examining the arousal hypothesis (Eysenck, 1967, 1981). In this respect, the arousal construct has had significant heuristic value even as the physiological processes that framed the construct diminished in importance. Individual differences in cortico-reticular activity that were posed as a plausible basis for differences in attention, motivation and learning that distinguished introverts and extraverts yielded to progress in the articulation of the physiological structures and neurochemical pathways that served those psychological processes. From the extensive body of research that was inspired by the arousal hypothesis, some reliable and replicable effects can be extracted that show a good convergence between the behavioural expressions of the extraversion trait and experimental effects that probe the causal bases of extraversion. These effects, which were observed with a wide range of psychological recording methods and under a variety of conditions, converge on differences between introverts and extraverts in their reaction to sensory stimulation and in their expression of motor activity.

In our review of this copious literature (Stelmack, 1990; 1997), two fundamental processes can be inferred that direct the attempt to elaborate the biological bases of extraversion. First, there is compelling evidence indicating that introverts are more reactive or sensitive to punctate physical stimulation than are extraverts (Stelmack, 1990). These effects appear to meld with the preference of introverts for quiet and solitude (Campbell & Hawley, 1982; Dornic & Ekehammar, 1990) and with their tendency toward withdrawal as a coping strategy in stressful social situations (Endler &

Parker, 1990). Second, introverts and extraverts are shown to differ in their expression of motor behavior on a variety of tasks that require a simple motor response, with extraverts tending to initiate faster and more frequent responses than introverts (Stelmack, 1985). These effects also appear consistent with the greater disposition of extraverts to spontaneity, social disinhibition, impulsiveness (Barratt & Patton, 1983; Eysenck & Eysenck, 1991; Newman, 1987) and general physical activity than introverts (Eysenck, Nias & Cox, 1982). In the present article, we pursue this line of inquiry into the biological bases of extraversion by reporting an event-related potential (ERP) analysis that explored the sensory, cognitive, and motor processes that have been implicated in individual differences in the extraversion trait.

In a previous study (Stelmack, Houlihan, & McGarry-Roberts, 1993), we observed that extraverts exhibited faster movement time (MT) than introverts on several elementary cognitive tasks, MT being a measure of the speed of motor response. There were no differences between the groups on these tasks in either reaction time, a measure of cognitive processing speed, or in the latency of the P3 component of ERPs, also a measure of cognitive processing speed, but one that is relatively independent of response production processes. The salient effect in this study, then, referred individual differences in extraversion to simple motor processes rather than to cognitive processing speed or to the analysis of components required for task performance. In the present project, our primary objective was to extend the examination of these individual differences in motor processes by manipulating response execution and selection demands. Specifically, in this article we report the analysis of event-related brain potentials that were recorded concurrently with response time measures during the performance of two tasks, a simple reaction time task that varied stimulus intensity and motor response demands, and a stimulus–response compatibility task that varied stimulus evaluation and response selection demands. The behavioural response measures were extensively analysed in a previous paper and are briefly summarized here (Doucet & Stelmack, 1997). In this present analysis, we focus on ERP measures that articulate differences in sensory reactivity, cognitive processing speed, and response execution, and we examine their relation to extraversion.

The evidence on which the rationale for this study is based is briefly reviewed from the perspective of individual differences between introverts and extraverts on motor, sensory, and cognitive tasks, and with regard to ERP measures that distinguish between sensory, motor, and cognitive processes during the performance of elementary cognitive tasks.

Reaction Time, and Movement Time, and Extraversion

There is an extensive literature indicating that individual differences in extraversion may be linked to differences in the expression of motor activity. On questionnaires, extraverts describe themselves as lively, active, and sociable (Eysenck & Eysenck, 1975, 1991), characteristics which are endorsed in their preferences for competitive and recreational activity (Hendry, 1975) and for interactions involving assertiveness and competition. Introverts, on the other hand, avoid interactions involving assertiveness and competition (Furnham, 1981). Extraverts also tend to speak first and for a greater proportion of time (Campbell & Rushton, 1978; Carment, Miles & Cervin, 1965). In experimental situations where the number of movements was counted, extraverts exhibited more frequent movements than introverts. For example, when given an opportunity to press buttons as often or as little as they wished, extraverts pressed more often than introverts (Howarth, 1964). When button presses provided auditory stimulation in an otherwise quiet environment, extraverts pressed buttons more frequently than introverts, despite the fact that they listened to the stimuli for shorter durations (Gale, 1969). In a task that varied the number of button presses required to change visual stimuli, extraverts pressed more often and at a faster rate than introverts (Brebner & Cooper, 1978). Similarly, on a simple reaction time task (Brebner & Flavel, 1978), and on a go/no-go task (Helmers, Young & Pihl, 1997), extraverts tended to make more commissive errors than introverts. These studies, which are exemplary rather than exhaustive, point to fundamental differences between extraverts and introverts in their expression of motor behaviour.

Faster reaction times for extraverts than for introverts were reported by several investigators using simple reaction time tasks (Buckalew, 1973; Keuss & Orlebeke, 1977; Mangan & Farmer, 1967; and Zhorov & Yermolayeva-Tomina, 1972), while others reported no overall differences between groups (Brebner & Cooper, 1974; Casal, Caballo, Cueto & Cubos, 1990; Gupta & Nicholson, 1985; Hummel & Lester, 1977; Hunt, Catalano, & Lombardo, 1996). Extraverts were also reported to have faster reaction times than introverts on a choice reaction time task (Thackray, Jones & Touchstone, 1974) and on a stimulus-response compatibility task (Brebner, 1990), though no overall differences were found on a go/no-go task (Brebner & Flavel, 1978). These disparities are somewhat difficult to reconcile, and some analysis of the experimental paradigms is warranted.

Response time can be decomposed to include, for example, components such as stimulus evaluation, response selection, and response execution. In research analysing the chronometry of mental ability, it is now common practice to distinguish response time in terms of reaction time (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. Reaction time and movement time can be differentiated by using an apparatus with a home button and response buttons, where RT is defined as the time from stimulus onset to the lift-off from the home button, and MT is defined as the time from lift-off to the press of a response button (Jensen & Munro, 1979). Studies using this RT/MT distinction find that extraverts have faster MTs than introverts (Barratt, 1967; Rammsayer, Netter & Vogel, 1993; Rammsayer, 1995; Stelmack, Houlihan, et al., 1993). RT, when measured as a lift-off, does not usually show a correlation with extraversion (but see Robinson & Zahn, 1988; Zahn, Kruesi, Leonard, & Rapoport, 1994).

In the context of information processing approaches to cognition, response time is the method of choice when manipulating cognitive load, stimulus evaluation demands, or response selection demands. RT is influenced to a much greater extent than MT by stimulus evaluation demands, and is more highly correlated with measures of mental ability than is MT. MT appears to be relatively independent of cognitive processes (Jensen, 1982; Houlihan, Campbell & Stelmack, 1994). As such, individual differences in MT are more easily attributed to differences in fundamental motor processes than to cognitive, pre-motor, cortical processes.

In the analysis of the behavioral response time measures (RT and MT) obtained in the present study, a salient effect was that in both tasks and across all conditions, the MTs of extraverts were substantially and consistently faster than those of introverts (Doucet & Stelmack, 1997). Further, the magnitude of the difference between groups remained constant despite increases in response button distance, indicating that the differences were at the level of movement initiation, rather than in the ballistic phase of the movement. There were no differences between extraversion groups on the RT measure. This effect clearly implicates fundamental, peripheral motor mechanisms in individual differences in extraversion.

In the present article, the analysis of extraversion and individual differences in RT and MT during simple reaction time and stimulus-response compatibility tasks is complemented by an analysis of event-related potentials (ERPs). This ERP analysis provides unique information about sensory reactivity and stimulus evaluation processes that are independent of response selection and execution.

Sensory Reactivity, Event-related potentials, and Extraversion

There is strong evidence from a variety of paradigms that introverts and extraverts differ in their reaction to stimulation. This has been shown with psychophysical measures of sensory thresholds, and with psychophysiological measures of skin conductance responses, startle and audiomotor reflexes, and ERPs (Stelmack, 1997; Stelmack & Houlihan, 1995). Briefly, the greater sensitivity of introverts is evident from their lower sensory thresholds (Siddle, Morrish, White & Mangan, 1969; Shigehisa, Shigehisa & Symons, 1973; Shigehisa & Symons, 1973; Stelmack & Campbell, 1974), lower pain thresholds (Barnes, 1975; Dubreuil & Kohn, 1986; Schalling, 1971), and lower noise thresholds (Dornic & Ekehammar, 1990). Introverts also display larger skin conductance responses to tones than extraverts (e.g., Smith, Concannon, Campbell, Bozman & Kline, 1990).

It is also important to note that there is some data indicating that these differences in responsivity to stimulation are evident in peripheral sensory nervous system processes. Effects that can be attributed to differences in sensory reactivity were observed with the startle response, a brainstem reflex elicited by abrupt acoustic stimuli and measured by the latency of the eye blink muscle activity. Introverts display faster startle response latencies than extraverts (Britt & Blumenthal, 1991; Corr et al., 1995) and larger response amplitudes than extraverts (Ljubin & Ljubin, 1990). Similarly, individual differences in sensory reactivity can be inferred from data reported in several studies using brainstem auditory evoked potentials (BAEPs). BAEPs develop during the first 10 ms of activity following the presentation of acoustic stimuli, and mark the time course of synaptic transmission along the brainstem auditory pathway. Introverts exhibit faster BAEP latencies than extraverts (Bullock & Gilliland, 1993; Stelmack, Campbell & Bell, 1993; Stelmack & Wilson, 1982; Swickert & Gilliland, 1998). Because BAEP latencies are faster when stimulus intensity is increased (Chiappa, 1990), it again appears that introverts are responding as if the stimulation is more intense for them than it is for extraverts. These BAEP data are not easily accounted for by differences in cortical activity and suggest that variation in extraversion involves differences in sensory processing at a more fundamental, peripheral level of the nervous system (Stelmack & Houlihan, 1995).

Event-related potential measures of the cortical activity that develops following simple, punctate physical stimulation also show larger responses for introverts than extraverts. In comparison to extraverts, introverts exhibited larger peak amplitudes for early ERP waves, in the range of 80-200 ms, to simple visual (Stenberg, Rosen & Risberg, 1990) and auditory stimulation (Bruneau, Roux, Perse & Lelord, 1984; Stelmack, Achorn & Michaud, 1977; Stelmack & Michaud-Achorn, 1985). ERPs within the first 200 ms are considered to be exogenous rather than endogenous, that is, their amplitudes are determined primarily by physical stimulus parameters such as pitch and intensity, rather than by the cognitive processing demands of the task (Coles, Gratton & Fabiani, 1990). In the present study, the signals to respond in the simple reaction time task are brief, moderate intensity tones (85 and 70 dB). It can be expected that the greater sensitivity of introverts than extraverts to physical stimulation may be expressed in larger amplitudes of these early components in the ERP waveforms that are recorded during the presentation of these tones.

Extraversion, Speed of Cognitive Processing, and Event-related Potentials

As previously noted, response time was a method of choice in a broad range of tasks investigating individual differences in extraversion. An unresolved issue is whether the faster response times observed for extraverts than for introverts are due to faster cognitive processing speed, or, as we have argued, to faster response execution (MT) processes. During the past 20 years, substantial progress has been made in the development of an alternate measure of cognitive processing speed. Specifically, the latency of the P3 wave of the ERP is purported to provide a measure of speed of cognitive processing that is relatively independent of response selection and execution processes. This was effectively demonstrated by Kutas, McCarthy and Donchin (1977) in a task that manipulated speed and accuracy instructions as well as semantic categorization difficulty. Speeded instructions decreased response time measures, but had no effect on P3 latency. Both P3 latency and response time increased with increased task demands, specifically categorization difficulty. Similar effects were observed on a Stroop task, where color names were printed in ink that was either compatible or incompatible with the word meaning. Incompatible stimuli increased response times, but not P3 latency (Duncan-Johnson, 1981). This effect also emerged in a task that manipulated both noise (irrelevant stimuli that flanked the target stimuli) within a stimulus and response compatibility. In that study, both response time and P3 latency were slower in noisy stimulus conditions. Response incompatibility also delayed both response time and P3 latency, but the effects of response incompatibility were far larger in response time measures than in P3 latency measures (Magliero, Bashore, Coles & Donchin, 1984).

Investigators have also examined whether individual differences in extraversion are evident in P3 latency measures, reasoning that if introverts are more cortically aroused than extraverts, this difference will manifest itself in faster cognitive processing speeds, and therefore faster P3 latencies. In the few studies that reported P3 latency effects in relation to extraversion, most found that there were no differences in P3 latency between introverts and extraverts (Cahill & Polich, 1992; Ditraglia & Polich, 1991; Ortiz & Maojo, 1993; Polich & Martin, 1992; Pritchard, 1989; Stenberg, 1994). One exception is a study using a stimulus-response compatibility task (Brebner, 1990), where introverts were reported to have faster P3 latencies than extraverts. This effect is consistent with the view that introverts are "geared to inspect", meaning that they derive excitation from stimulus analysis, disposing them to continue in or augment activities involving stimulus analysis (Brebner, 1983, 1990).

In this study, ERPs were recorded concurrently with RT measures as subjects performed simple reaction time and stimulus-response compatibility tasks. Because the latency of the P3 component of the ERP provides a measure of speed of cognitive processing that is independent of response selection and execution, it is a discrete measure that can help clarify whether individual differences in extraversion involve differences in cognitive processing speed.

Method

Participants

Sixty-seven female university students volunteered their participation for the experimental sessions. The age of the participants ranged from 18 to 30 years (M=22, SD=3). The participants were selected on the basis of scores on the Extraversion scale of the Eysenck Personality Questionnaire - Revised (EPQ-R; Eysenck & Eysenck, 1991) to form 3 groups, with introverts scoring between 0-11, ambiverts between 13-17, and extraverts between 18-23. The mean scores of the three Extraversion groups on the EPQ-R scales are reported in Table 1, and the intercorrelations between the personality scales of the EPQ-R are reported in Table 2. There were no significant differences in age or personality score distribution between the samples for each task. Of the 67 participants, 50 completed both the simple reaction time task and stimulus-response compatibility tasks. Seven participants took part only in the simple reaction time task (N=57, 19 each of extraverts, ambiverts, and introverts) and 10 others only in the stimulus-response compatibility task (N=60, 20 each of extraverts, ambiverts, and introverts).

Table 1. Mean Scores (and Standard Deviations) on the Personality Scales for the Participants

Simple Reaction Time task (N=57).

	Extraversion	Neuroticism	Psychoticism	Lie
Extraverts	20.4 (1.3)	11.4 (5.3)	5.3 (3.5)	6.3 (4.1)
Ambiverts	15.2 (1.5)	11.3 (3.3)	5.2 (3.4)	7.4 (4.0)
Introverts	5.8 (2.9)	13.8 (5.1)	5.7 (4.3)	9.5 (4.6)

Stimulus-Response Compatibility task (N=60)

	Extraversion	Neuroticism	Psychoticism	Lie
Extraverts	20.4 (1.2)	12.6 (5.1)	5.4 (3.4)	6.5 (4.1)
Ambiverts	15.6 (1.5)	11.1 (3.3)	5.3 (3.4)	7.5 (4.2)
Introverts	6.3 (2.6)	14.6 (4.9)	5.2 (3.0)	9.2 (4.7)

Table 2. Intercorrelations of Personality Scales for the Samples

Simple Reaction Time task (N=57).

	Extraversion	Neuroticism	Psychoticism	Lie
E	-----			
N	-.20	-----		
P	-.11	.17	-----	
L	-.29 *	-.18	-.27 *	-----

* P<.05

Stimulus-Response Compatibility task (N=60).

	Extraversion	Neuroticism	Psychoticism	Lie
E	-----			
N	-.22	-----		
P	-.004	.30 *	-----	
L	-.25	-.23	-.26 *	-----

* P<.05

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. Participants were non-smokers, and were instructed to restrain from ingesting caffeine for four hours prior to testing.

Response Apparatus

A response box was constructed with a home button, and target 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 target button. In the simple reaction time task, stimuli were presented in blocks that required the use of a different target button located at either 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 two target buttons, each at 7 cm and 30° to the left and right of the home button. Templates were used to reveal only the buttons used in that block of trials and mask the unused buttons. The same finger that was kept on the home button was used for responding.

Procedure

Participants were seated 0.5 meters 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. Participants were also instructed to respond as quickly and as accurately as possible.

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 3000 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 visually focus on the response button being used, and to avoid shifting their gaze to the home button.

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, i.e., 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 were to respond by pressing a target button located in the same direction as the middle arrow pointed (compatible response). If the cue word was "OPPOSITE", participants were to respond by pressing the target button located in the direction opposite from where the middle arrow pointed (incompatible response). Thus, there were four conditions, congruent arrays with 1) compatible and 2) incompatible instructions, and incongruent arrays with 3) compatible and 4) incompatible instructions.

The instructional 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 word appeared

1000 ms later, resulting in a trial to trial interval of 2400 ms. The presentation order of the 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 two to five minutes 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 visually focus on the center of the computer monitor, and to avoid looking at the response box. Participants did not have any problems complying with this request.

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.

EEG Recordings

The electroencephalogram (EEG) was recorded from Ag/AgCl electrodes affixed to the midline frontal (Fz), central (Cz) and parietal (Pz) scalp sites. The horizontal electrooculogram (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 infra-orbital ridges of the left eye. The reference electrode was on the left mastoid. Interelectrode impedances were below 2 kOhms. The high filter was set at 30 Hz, and the time constant at two seconds. The EEG and EOG were sampled at 512 Hz and stored continuously to hard disk. All recordings were performed with InstEP™ software. 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 FFT algorithm. Single trials were reconstructed beginning 100 ms prior to stimulus onset and continuing for 1000 ms following it. 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.

Inspection of the grand average waveforms for the ERPs obtained from the simple reaction time task indicated larger negative amplitudes for a wave that developed about 100 ms (N1) following the onset of the tone that was a signal to respond. The latency of the N1 component was scored by determining the maximum negative amplitude between 75 and 175 ms at the Fz site. N1 amplitudes were measured relative to a 100 ms prestimulus baseline. A positive polarity peak at approximately 380 ms (P3) was evident in individual simple reaction time waveforms but was masked in the grand average waveforms. The latency of the P3 component was scored by determining the maximum positive amplitude between 275 and 550 ms on individual averaged waveforms at the Pz electrode site. P3 amplitudes were measured relative to a 100 ms prestimulus baseline.

On the stimulus-response compatibility task, the waveforms included the time for the presentation of both the instructional cue word and the stimulus array. The latency of the P3 component was scored by determining the maximum positive amplitude between 275 and 600 ms on individual averaged waveforms at the Pz electrode site. P3 amplitudes were measured relative to the 100 ms prestimulus baseline prior to the presentation of the stimulus array.

Results

Simple Reaction Time Task

The simple reaction time task was designed to manipulate response execution demands under conditions where cognitive processing demands were minimal. On each trial, a simple tone signaled the participant to respond.

RT, MT, P3 and N1 data were analysed using three-way ANOVAs, with group (extravert, ambivert, introvert) as a between subjects factor, and with repeated measures on response button distance (0, 7, 15, and 23 cm) and stimulus intensity (70, 85 dB SPL) factors. The effects of the order in which the response button distances were presented were analysed in an additional three-way ANOVA, with Order as the between subjects factor, and repeated measures on response button 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. All post-hoc tests were performed with Tukey's Honest Significant Difference procedure.

Performance Measures

The performance measures, RT and MT, for the extraversion groups on the simple reaction time task that were analysed in our previous report (Doucet & Stelmack, 1997), are summarized in Table 3. There were no significant main effects or interactions related to the order in which the response button distances were used (F<1). There were no differences in RT between the groups. MT, however, was consistently faster among the extraverts than introverts at all response button distances. The difference between groups remained constant as response button distance increased, rather than increasing as the distance increased. This indicates that the differences between introverts and extraverts occur at the initial phase of the movement, not in the ballistic phase of moving to the response button.

Table 3. Mean (and Standard Deviations) of RTs and MTs (in msec) for the three Extraversion Groups on the Simple Reaction Time Task.

			Introverts	Ambiverts	Extraverts
	7 cm	85 dB	280 (34)	270 (35)	276 (43)
		70 dB	294 (34)	284 (41)	286 (48)
RT:	15 cm	85 dB	289 (33)	280 (32)	276 (30)
		70 dB	300 (41)	295 (38)	288 (37)
	23 cm	85 dB	283 (32)	279 (25)	278 (28)
		70 dB	295 (38)	290 (34)	292 (36)
	7 cm	85 dB	192 (42)	153 (40)	150 (33)
		70 dB	192 (42)	156 (41)	149 (33)
MT:	15 cm	85 dB	260 (52)	219 (48)	215 (49)
		70 dB	259 (52)	218 (48)	219 (50)
	23 cm	85 dB	299 (63)	266 (56)	257 (61)
		70 dB	295 (67)	265 (57)	256 (63)

N1 Component

In Figure 1, the mean amplitude of the N1 component of the ERP waveform at Fz to the auditory tones is illustrated for the three extraversion groups across each distance. Figure 2 presents the grand average waveforms for the conditions where a button press was required.

There were no significant group differences in the latency of the N1 wave ($F<1$), nor was there any intensity effect ($F<1$), or response button distance effect, $F(3,138)=1.2$, $P<.31$. Interactions were not significant.

N1 amplitudes elicited by the 85 dB tones (-6.2 μV) were larger than those elicited by the 70 dB tones (-5.8μV), F(1,46)=4.8, P<.03, an effect illuminating the sensitivity of N1 to differences in stimulus intensity. Amplitudes were also larger in the simple lift-off (0 cm) condition than in the conditions where a button press was required, F(3,138)=4.8, P<.003. Post-hoc analyses confirmed that the button press conditions did not differ amongst themselves. A salient effect was that introverts displayed larger N1 amplitudes (-7.9 μV) than did ambiverts (-5.5 μV) and extraverts (-4.6 μV), F(2,46)=5.29, P<.009. Post hoc analysis revealed that this group effect was significant at each response button level and at both stimulus intensities. All interactions were not significant (F<1). In summary, the larger N1 amplitudes to the tones for introverts than extraverts are indicative of greater sensory reactivity to punctate stimuli for introverts than extraverts.

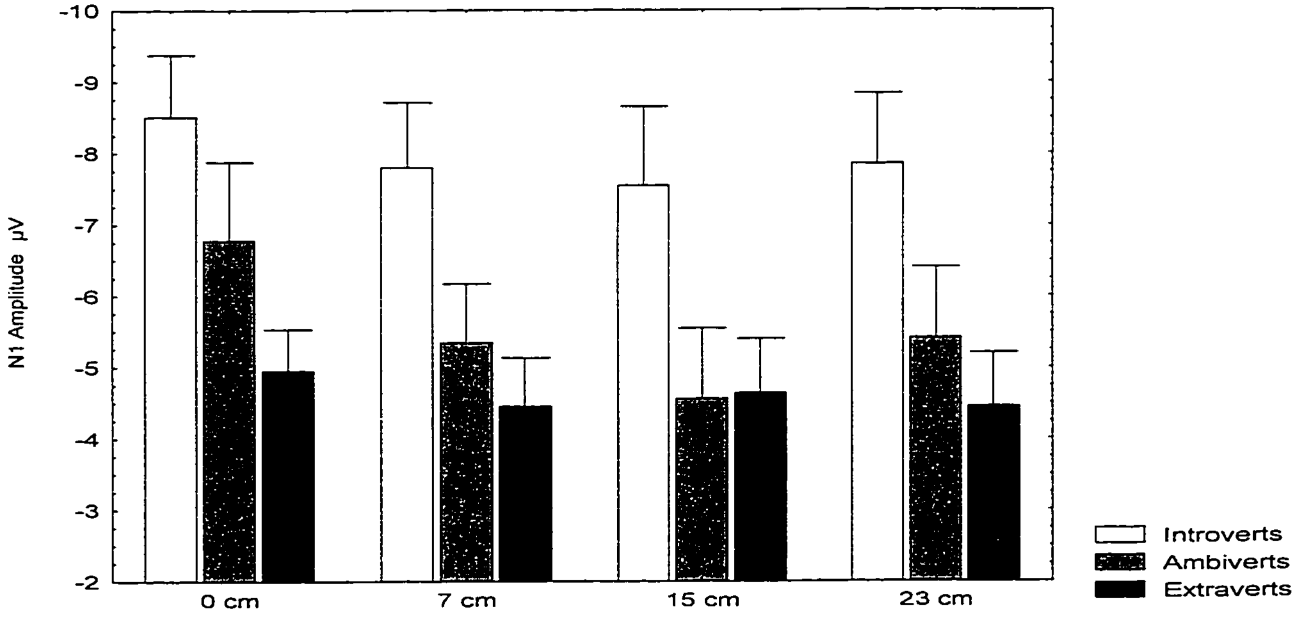

Figure 1. Mean N1 amplitude and standard errors at Fz for each group to target stimuli during the simple reaction time task. Stimulus intensities are combined. Introverts exhibit significantly larger amplitudes than extraverts across all distances.

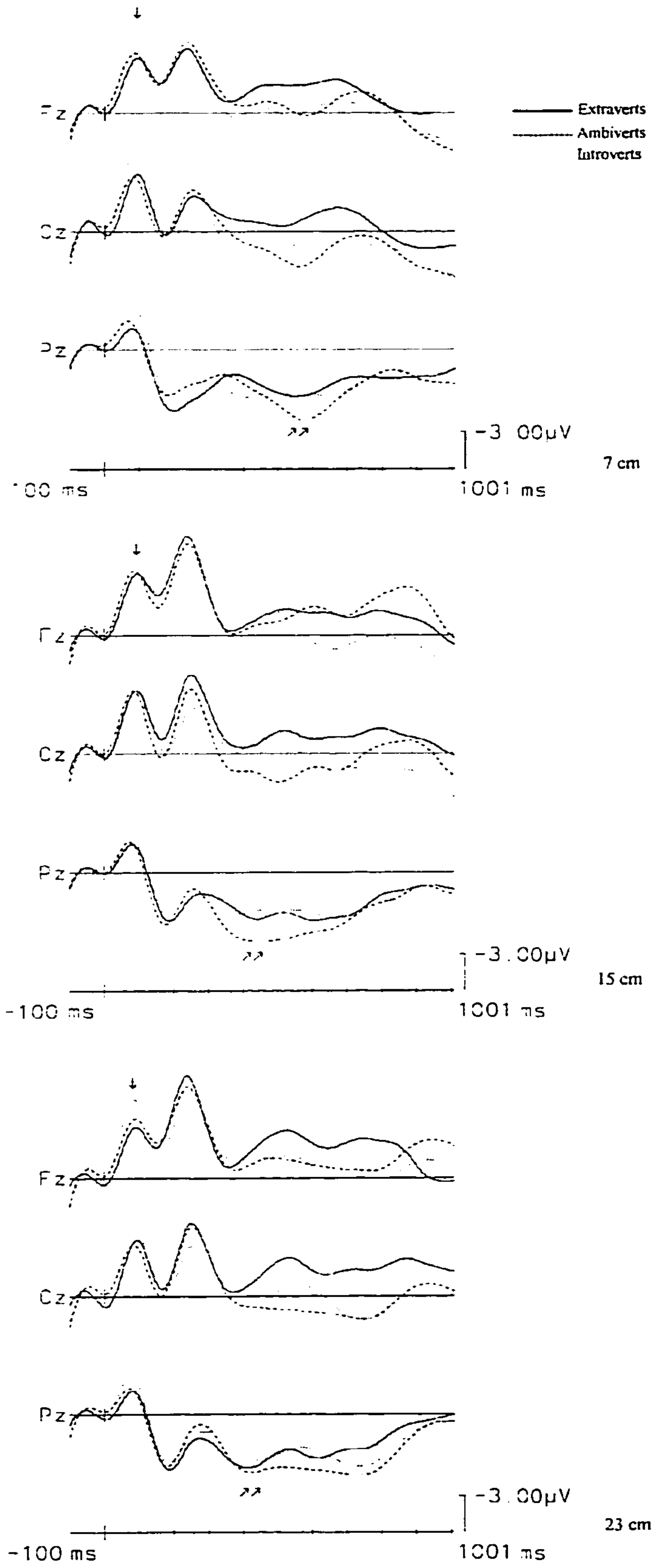

Figure 2. Grand average waveforms to target stimuli during the simple reaction time task. Stimulus intensities are combined. Introverts exhibit significantly larger N1 amplitudes than extraverts across all distances. N1 is indicated by one arrow (↓). No effect of extraversion group is evident for P3 latency. P3 latency is indicated by two arrows (↗↗).

P3 Component

Because the P3 component was not consistently visible in the individual records of the simple lift-off (0 cm) condition, it was only scored for the conditions in which the lift-off was followed by a button press. The scalp distributions of the P3 waves followed a linear increase in amplitude from frontal to parietal midline sites. The morphology and latencies observed in the waveform were comparable to those observed by Falkenstein, Hohnsbein, and Hoormann (1993), McGarry-Roberts, Stelmack and Campbell (1992), and Ritter, Simson and Vaughan (1972) using similar stimulus parameters and task requirements.

There were no significant main effects or interactions for either P3 amplitude or latency that were related to the order in which the response button distances were used ($F<1$). Effects of stimulus intensity approached significance, $F(1,54)=3.69$, $P<.06$, with the 85 dB tones tending to elicit larger P3 amplitudes than the 70 dB tones. Similarly, effects of response button distance also approached significance, $F(2,108)=2.90$, $P<.06$, $\epsilon=.86$, with the further response button distances tending to elicit larger P3 amplitudes than the closer response button distances. There were no significant differences in P3 amplitude for groups ($F<1$), nor were there any significant interactions.

Figure 2 shows grand average waveforms for each group at each response button distance, and Figure 3 graphs the P3 latency means. There was no effect of group on P3 latency ($F<1$).

The 85 dB tones elicited faster P3 latencies than the 70 dB tones (373 ms vs 401 ms), $F(1,54)=28.5$, $P<.0001$. Similar intensity effects between stimulus intensity and P3 latency were previously observed (Papanicolaou, Loring, Raz & Eisenberg, 1985; Sugg & Polich, 1995). P3 latency increased with increasing response button distance, $F(2,108)=10.6$, $P<.0001$, $\epsilon=.85$. There were no significant interactions.

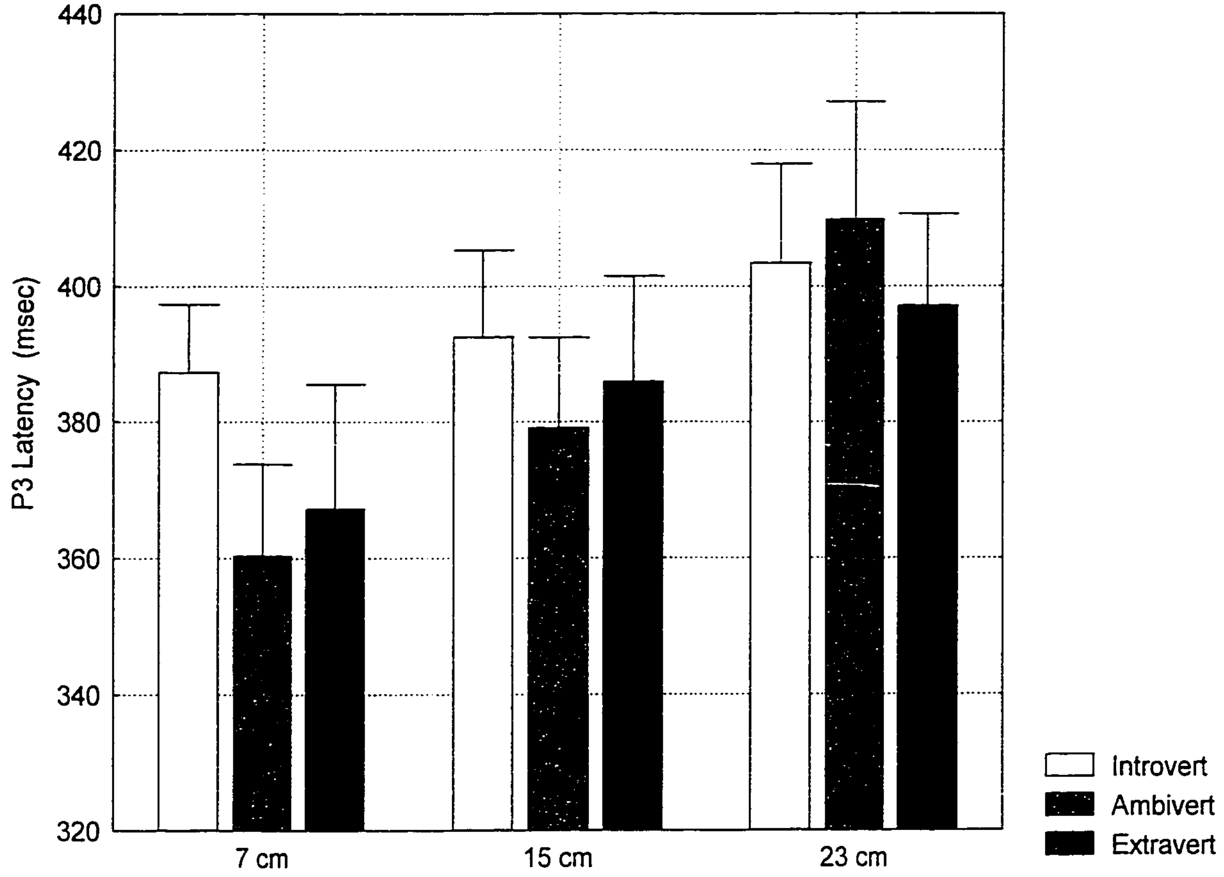

Figure 3. Mean P3 latency and standard errors at Pz for each group to target stimuli during the simple reaction time task. Stimulus intensities are combined. Groups are not significantly different from each other.

Table 4 presents correlations between extraversion and RT, MT, P3 latency, and N1 amplitude (disregarding the negative sign) for the simple reaction time task. The strength of the correlations between extraversion and the dependent measures MT and N1 amplitude increases our confidence in the interpretation that fundamental motor mechanisms and sensory reactivity are implicated in individual differences in extraversion.

Table 4 Correlations Between Extraversion Scores and Dependent Measures on the Simple Reaction Time task

	RT	MT	P3 Latency	N1 Amplitude
Response Button Distance				
0 cm	-.07		-.03	-.32**
7 cm	-.05	-.43***	-.17	-.42**
15 cm	-.10	-.36**	-.12	-.32**
23 cm	-.03	-.32**	-.01	-.36**

In summary, the faster MTs for extraverts than introverts refers individual differences in extraversion to differences in fundamental, peripheral motor processes. The larger N1 amplitudes for introverts than extraverts affirms that introverts are more reactive to auditory stimulation than are extraverts. Although P3 latency increased with increases in stimulus intensity, no individual differences between introverts and extraverts were observed with this measure on this simple reaction time task.

Stimulus-Response Compatibility Task

The stimulus-response compatibility task was designed to assess individual differences with respect to response selection and cognitive processing speed when stimuli and responses were in competition for processing resources. Arrow arrays with flankers congruent and incongruent to middle arrows were used to manipulate cognitive processing demands.

In this stimulus-response compatibility task, RT, MT, and P3 data were analysed with three-way ANOVAs, with group (extravert, ambivert, introvert) as a between subjects factor, with repeated measures on stimulus congruency (congruent, incongruent) and response compatibility (compatible, incompatible) factors. All post-hoc tests were performed with Tukey's Honest Significant Difference procedure.

Performance Measures

Table 5 presents the performance data for the stimulus-response compatibility task. RTs were faster to arrow arrays with congruent flankers than to arrays with incongruent flankers, and faster when response instructions cued compatible responses than when they cued incompatible responses. Although there was no main effect of group (F<1) in the RT measures, there was a three-way interaction between group, stimulus congruency and response compatibility. The RTs of extraverts were faster than those of introverts and ambiverts in the congruent incompatible condition, F(2,57)=4.30, P<.018. This indicates that when stimuli are congruent, extraverts react to the demands of response incompatibility faster than introverts or ambiverts. Post hoc analysis indicated that there were no significant differences among groups in the other three conditions. Given that this is an isolated effect, emerging in a three-way interaction, it is difficult to attribute the effect to the influence of either stimulus congruency or response incompatibility, and is perhaps best regarded as a spurious effect. This is underscored by the failure of the correlation between extraversion and RT for this condition to exceed the .05 level of confidence, r= -.18 (see Table 6). On the other hand, as indicated in our previous report, significant correlations between extraversion and omission errors were observed for both the congruent incompatible (r= 0.25, P=.05) and the incongruent incompatible (r= 0.29, P=.03) conditions. This suggests that introverts had more difficulty than extraverts in initiating responses in the incompatible conditions.

Across all conditions, the MTs of extraverts were between 38 and 41 ms faster than those of introverts. MTs were also faster to arrays with congruent flankers than to incongruent arrays. This effect was small (9 ms) compared to the delays observed in RT (65 ms), and indicates that MT is only minimally affected by stimulus evaluation processes.

Table 5.

Mean (and Standard Deviations) of RTs and MTs (in msec) for the three Extraversion Groups on the Stimulus-Response Compatibility Task.

		Introverts	Ambiverts	Extraverts
	Congruent Compatible	494 (59)	486 (82)	485 (55)
	Congruent Incompatible	543 (85)	536 (93)	510 (58)
RT:	Incongruent Compatible	573 (85)	568 (107)	556 (83)
	Incongruent Incompatible	580 (96)	590 (112)	578 (92)
	Congruent Compatible	183 (50)	160 (36)	144 (25)
	Congruent Incompatible	184 (49)	161 (36)	146 (25)
MT:	Incongruent Compatible	196 (69)	171 (42)	155 (31)
	Incongruent Incompatible	189 (66)	171 (41)	151 (29)

These data replicate the effect of faster MTs for extraverts observed in the simple reaction time task and endorse the view that individual differences in extraversion are referred to differences in fundamental motor processes. Further, to the extent that RT is a measure of speed of cognitive stimulus evaluation, the data provide little support for the hypothesis of differences in the speed of stimulus evaluation processing between extraversion groups.

P3 Component

Arrow arrays with congruent flankers elicited larger P3 amplitudes (3.73μV) than did incongruent arrays (2.53μV), F(1,57)=22.46, P<.0001. Also, compatible response conditions elicited larger amplitudes (4.59μV) than did incompatible response conditions (1.67μV), F(1,57)=74.65, P<.0001. 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). There were no group differences in P3 amplitude (F<1). No interactions were observed (F<1).

Figure 4 graphs the means for P3 latency for each group and condition, and Figure 5 shows grand average waveforms. Congruent arrow arrays elicited faster P3 latencies (362 ms) than did incongruent arrays (411 ms), F(1,57)=44.80, P<.0001. This effect confirms the sensitivity of P3 latency to stimulus evaluation processes. There were no significant differences in P3 latency between the compatible and incompatible response conditions, F(1,57)=1.71, P<.20, confirming that P3 latency is independent of response selection demands under these conditions. There were there no group differences in P3 latency, F(2,57)=1.51, P<.23. There were no interactions between group and congruency (F<1), group and compatibility (F<1), or congruency and compatibility, F(1,57)=2.13, P<.15. There was a three-way interaction between group, congruency, and compatibility, F(2,57)=3.44, P<.04. Under compatible response conditions all groups show longer latencies for incongruent than for congruent stimuli. This increase is significant for extraverts (72 ms) and ambiverts (78 ms), but not for introverts (23 ms). Post hoc analyses, however, confirmed that when each condition is examined separately, the three groups did not differ from each other. These results indicate that although P3 latency is sensitive to the cognitive processing demands of the task, group

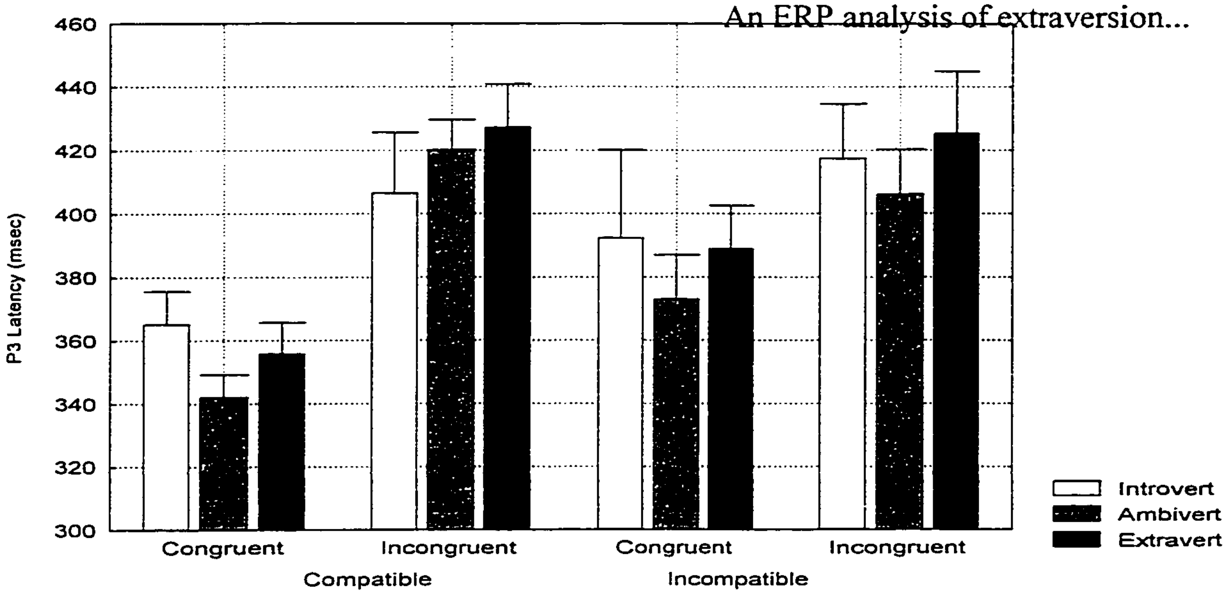

Figure 4 Mean P3 latency and standard errors at Pz for each group on the stimulus-response compatibility task. In each condition, the groups are not significantly different from each other.

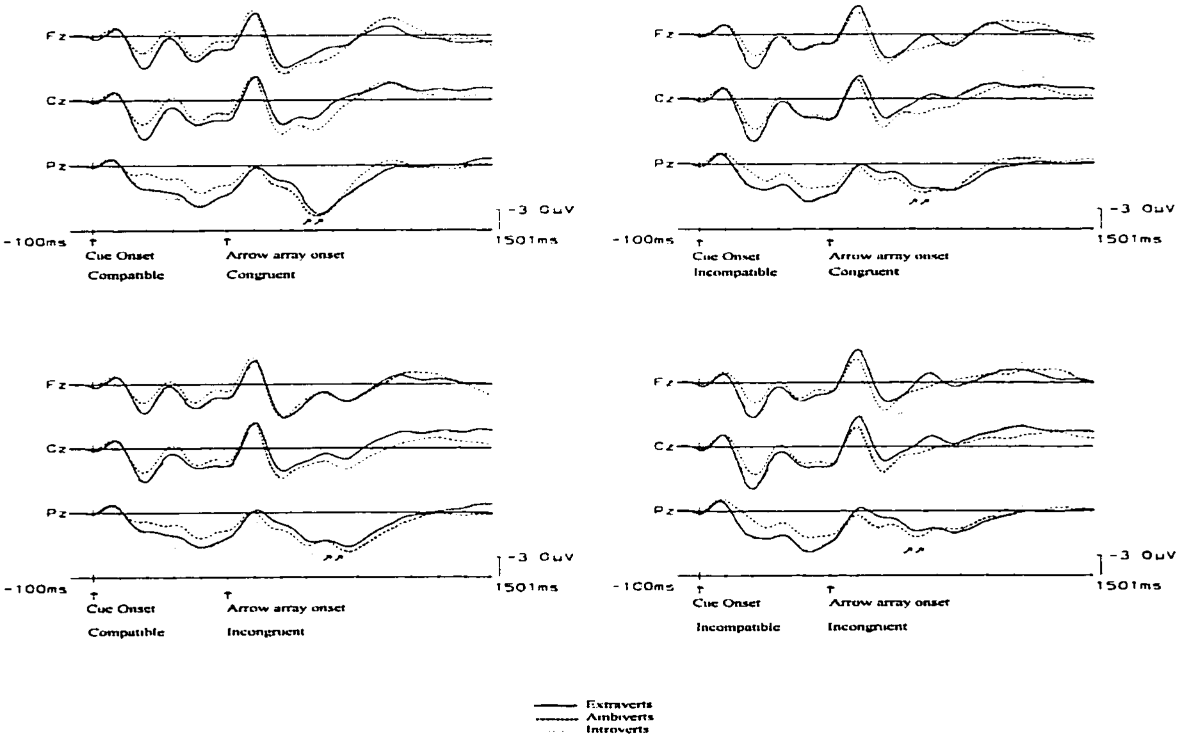

Figure 5. Grand average waveforms for each group and condition during the stimulus-response compatibility task. Groups are not significantly different from each other. P3 is indicated by two arrows (↗↗).

Table 6 presents correlations between extraversion and RT, MT, P3 latency, and N1 amplitude (disregarding the negative sign) for the stimulus-response compatibility task. The correlations between extraversion, RT, and MT echo the pattern observed in the simple reaction time task. The correlations between extraversion and P3 latency, however, suggest that under some conditions, there are differences in the speed of stimulus evaluation processing between introverts and extraverts. These conditions, congruent-incompatible (Opposite, > > > > >) and incongruent-compatible (Same, > > < > >), are the two variations in which the flankers are pointing in a direction opposite to the response button location. The significant positive correlations in these conditions suggests that extraverts may be more influenced by the flankers. This effect was not evident in RT measures.

Table 6 Correlations Between Extraversion Scores and Dependent Measures on the Stimulus-Response Compatibility task

	RT	MT	P3 Latency
Congruent Compatible	-.09	-.43***	-.07
Congruent Incompatible	-.18	-.42***	.28*
Incongruent Compatible	-.10	-.36**	.26*
Incongruent Incompatible	-.04	-.34**	.11

*<.05, **<.01, ***<.001

In summary, the evidence provided by P3 latency measures on the stimulus-response compatibility task is equivocal. The ANOVA analysis indicates that overall, extraverts are not different from introverts in speed of cognitive processing. The correlation analysis, however, indicates that this conclusion should be tempered, as some conditions elicit systematic variations among introverts and extraverts.

Discussion

There is abundant evidence in the literature for greater sensory reactivity in introverts than in extraverts, including lower sensory thresholds, larger skin conductance responses, and larger ERP amplitudes. In this study, individual differences in sensory reactivity were evident in the amplitude of a negative ERP wave to auditory tones that signaled the participants to respond in the SRT task. N1 amplitudes were larger to the higher intensity than lower intensity tones, an effect that demonstrates the sensitivity of this component to changes in the intensity of acoustic stimuli (Beagley & Knight, 1967; Picton, Woods, Baribeau-Braün & Healey, 1977; Rapin, Schimmel, Tourk, Krasnegor & Pollak, 1966). The amplitude of N1 to the tones was larger for introverts than for extraverts, confirming that introverts react as if the stimulus is more intense for them than it is for extraverts. Again, the greater reactivity to punctate stimulation for introverts than extraverts observed in this paradigm is consistent with the greater reactivity of introverts than extraverts observed with several psychophysical and psychophysiological recording procedures and expressed in a variety of social behaviours, including aversion to noise (Dornic & Ekehammar, 1990).

A number of authors have attempted to explore extraversion in terms of cognitive information processing models (Matthews & Amelang, 1993; Matthews, Davies & Lees, 1990; Matthews & Harley, 1993). In this work, cognitive processing speed was often indexed by response time measures. There is reason, however, to be cautious in using response time measures that do not differentiate between RT and MT. Because RT has strong negative correlations with mental ability, in the range of -.2 to -.6 (Jensen, 1997), the influences of mental ability will be confounded in designs where both RT and MT are elements of the response time variable but are not measured independently. This may, in part, explain the absence of consistent effects when using cognitive tasks to examine individual differences in extraversion (Matthews & Amelang, 1993; Matthews, Davies & Lees, 1990; Matthews & Harley, 1993).

In measuring cognitive processing speed, the latency of the P3 component of the ERP is a well established measure that complements behavioural RT measures, and in addition, is relatively independent of the influence of response selection and response execution. As such, P3 latency provides a more discrete measure of cognitive processing speed than does RT.

ERPs and response time were recorded in an early study that examined extraversion using a stimulus-response compatibility task (Brebner, 1990). In that study, introverts exhibited faster P3 latencies than extraverts. Spatial compatibility effects that are usually observed in the literature were not evident (Leuthold & Sommer, 1998; Nandrino & El Massioui, 1995; Ragot, 1984; Ragot & Lesèrve, 1986; Ragot & Renault, 1981; Renault, Fiori & Giami, 1988; Sommer, Leuthold & Hermanutz, 1993; Valle-Inclán, 1996a, 1996b). Thus, the reliability of the personality effects may be questioned.

In the present study, RTs and P3 latencies were faster to congruent than to incongruent arrow arrays, replicating the effects in the literature and underscoring the sensitivity of these measures to stimulus evaluation processing demands (Bashore, 1990; Magliero et al., 1984; McCarthy & Donchin, 1981). As expected, RTs were faster to instructions cuing compatible responses than incompatible responses, and P3 latency was unaffected by response incompatibility. Again, these findings are in agreement with studies that cued compatibility by using words that precede the presentation of the target stimulus (Magliero et al., 1984; McCarthy & Donchin, 1981). Although overall differences between extraversion groups were not present in either the RT measure or the P3 latency measure, two conditions elicited correlations between extraversion and P3 latency. These conditions were those in which the flankers impeded stimulus processing in extraverts.

As detailed in our previous report (Doucet & Stelmack, 1997), extraverts exhibited faster MTs than introverts across all conditions on both the simple reaction time and stimulus-response compatibility tasks. This effect replicates other studies of extraversion using the MT measure (Barratt, 1967; Rammsayer, 1995; Rammsayer et al., 1993; Stelmack, Houlihan et al., 1993). Because the magnitude of the MT differences between introverts and extraverts was constant across three levels of response button distance, the differences were attributed to the initial phase of the movement, rather than to the ballistic phase. These findings indicate that the differences are at the level of motor initiation rather than in ballistic movement. The MT data also converge with a plethora of observations that introverts and extraverts differ in their expression of motor activity.

To the extent that RT and MT distinguish between cortical response selection processes and peripheral response execution processes, individual differences in MT between introverts and extraverts are more easily attributed to differences in fundamental, peripheral motor processes. Related evidence supporting this conclusion may be drawn from a study assessing spinal motoneuronal excitability, where extraverts were found to have reduced levels of monosynaptic reflex recovery compared to introverts (Pivik, Stelmack & Bylsma, 1988; Stelmack & Pivik, 1996). This finding is more easily attributed to peripheral mechanisms than to differences in central, cortical arousal mechanisms.

The paradigms used in this study could be usefully adapted to explorations of motor processes from other perspectives. For example, an elegant study by Rammsayer et al., (1993) explored the neurochemistry that may underlie extraversion. In their study, an agent (AMPT) that reduces the synthesis of dopamine was administered, and found to increase both RT and MT in introverts, but not in extraverts. As there is also some evidence that dopamine regulates the probability and strength of behavioural responses to sensory input (Depue, Luciana, Arbisi, Collins & Leon, 1994; Le Moal & Simon, 1991), some aspects of the dopaminergic system may represent an important link between the sensory and motor effects implicated in extraversion.

In summary, there is little evidence for differences in cognitive processing speed among introverts and extraverts in this study. Individual differences in extraversion are relatively consistent, however, in sensory reactivity and in motor initiation, with introverts reacting more strongly to punctate stimulation, and extraverts moving more quickly than introverts. These observations suggest that peripheral sensory and motor processes may be important factors in understanding the physiological basis of individual differences in extraversion.

End chapter 3.

Dissertation Summary and Conclusions

The preceding three chapters were intended to explore the sensory and motor bases for individual differences in extraversion. Variations in MT were elicited by manipulating movement extent, and extraverts were observed to be consistently faster than introverts. Further, these differences were in the initiation of the movement, rather than in the ballistic phase. Although it would be presumptuous to attribute the individual differences in extraversion solely to differences at the level of the peripheral nervous system, they are probably more influenced by peripheral than cortical processes, or at least they are easier to account for in terms of peripheral processes than cortical processes.

The finding of MT differences between introverts and extraverts suggests that in previous studies, which used undifferentiated response time measures and found faster "reaction times" in extraverts, the effects were due to the MT rather than the RT component. Also, to the extent that RT indexes speed of cognitive processing, the data provide no evidence for differences in cortical, cognitive processing.

The convergence of the RT measure with P3 latency was largely as expected, with both being faster to the louder tones in the simple reaction time task. Also, in the stimulus-response compatibility task, both were delayed by target stimuli flanked by incongruent arrows, but only RT was delayed by response incompatibility.

An unexpected finding was that on the simple reaction time task, P3 latency increased with increasing response button distance. One problem, however, was that the effect was not clearly visible on grand average waveforms. This left us with more questions than answers, and necessitated two small experiments. The first of these two small *N* experiments used the oddball paradigm. It was hoped that by using a go/no go task instead of a simple reaction time task, P3 amplitude would increase and be clearer in grand averages. P3 amplitude did indeed increase, but the effect of increasing response button distance disappeared. Surmising that the disappearance may have been due to the change in task demands of the go/no go paradigm, the simple reaction time task was again employed in a second small *N* experiment. This time, in order to increase P3 amplitude so it would be clearer in the grand averages, the stimuli were comprised of 25 % rare targets, and 75% frequent targets. This manipulation was effective, as P3 latency once again increased with increasing response button distance, and the effect was visible in grand averages. It was concluded that the effect emerges only when stimulus evaluation demands are negligible, and although it is an interesting effect, it would likely not be a confounding influence in most paradigms using P3 latency.

P3 latency interactions with extraversion were examined in order to evaluate whether there were individual differences in speed of cognitive processing. This was considered relevant to the cortical and peripheral bases of extraversion. Many hypotheses derived from the cortical arousal construct reasoned that if introverts have higher levels of arousal, they should have faster P3 latencies. In this analysis, there were no differences between introverts and extraverts in P3 latency. The pattern of evidence for individual differences in extraversion in speed of cognitive processing suggests that cortical arousal does not differentiate introverts and extraverts in any systematic way. The correlation between extraversion and P3 latency on the stimulus-response compatibility task leads to the question of whether introverts and extraverts have different strategies or patterns in perceptual processing.

Introverts were observed to display larger N1 amplitudes than extraverts. This was considered consistent with greater sensory reactivity. Differences in N1 amplitude are often attributed to differences in attentional mechanisms. The findings from this study, however, are difficult to attribute to attention as attentional demands were not manipulated, and there were no differences between introverts and extraverts on other measures that vary with attention, specifically, P3 amplitude, RT and response accuracy.

In summary, there is little evidence for differences in cognitive processing speed among introverts and extraverts in this study. Individual differences in extraversion are relatively consistent, however, in sensory reactivity and in motor initiation, with introverts reacting more strongly punctate stimulation, and extraverts moving more quickly than introverts. These observations suggest that the peripheral nervous system is implicated in individual differences in extraversion.

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Statement of Authority

I am the first author and Robert Stelmack is the second author on the three papers prepared for publication that constitute the body of this manuscript. The project was developed from the well established research program of Dr. Stelmack. I prepared drafts of the articles, and Dr Stelmack provided editorial guidance for their improvement.