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# Trail Making Test, Part B as a Measure of Executive Control: Validation Using a Set-Switching Paradigm*

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## ABSTRACT

Recent controversy surrounds the use of the Trail Making Test as a measure of cognitive flexibility, given that the Trail Making Test, Part B (TMT-B) also differs from Part A (TMT-A) in factors of motor control and perceptual complexity. The present study compared performance in the TMT and a set-switching task in order to test the assumption that cognitive flexibility is captured in TMT-B performance. Set-switching tasks have low motor and perceptual selection demands, and therefore provide a clearer index of executive function. In this study, participants made category judgments for digits, letters, or symbols across a series of trials, and performance for consecutive same-task trials was compared with task-switch trials. Results of the set-switching task indicated significant switch cost, but only for the situation of task alternation (e.g., an ABA series), suggesting that task-set inhibition may play a role in this effect. Alternating-switch cost was significantly correlated with TMT-B performance, especially with the TMT-B to TMT-A ratio (B/A). Cost for alternating switches was especially large for participants with B/A ratio > 3. These results provide direct evidence that the B/A ratio of performance in the TMT provides an index of executive function.

The ability to direct action and thought to selected goals is vitally important to human functioning. Both maintaining focus on a single goal (e.g., continuing to concentrate on work despite fatigue, hunger, or anxiety), and alternating attention between two simultaneous goals (e.g., entertaining the baby while making dinner or conversing while driving) are essential for everyday performance. Both of these abilities can be impaired with brain injury, and neuropsychological tests are commonly used to assess both sustained attention and task alternation abilities. The Trail Making Test is probably the most widely used instrument to assess the latter.

The Trail Making Test was originally designed as part of the Army Individual Test Battery (1944) and is now included in several general and specific-purpose neuropsychological test batteries (e.g., Halstead-Reitan Battery, Reitan, & Wolfson, 1993; Multicenter AIDS Cohort Study Battery, Selnes et al., 1991; Individual Neuropsychological Testing for Neurotoxicity, Singer, 1990, see also Crossley, Arbuthnott, & Semchuk, 1997). The Trail Making Test is an efficient and sensitive instrument that is easily administered, and which reliably discriminates between normal individuals and those with brain impairment (Lezak, 1995; Stuss, Stethem, Hugenholtz, & Richard, 1989). The test is given in two parts: Trail Making, Part A (TMT-A) involves drawing a line connecting consecutive numbers from 1 to 25. Part B (TMT-B) involves drawing a similar line, connecting alternating numbers and letters in sequence (i.e., 1-A-2-B and so on). The time to complete each 'trail' is recorded. In the stan-

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dardized administration procedure, examiners point out errors as they occur, and error-correction influences the time to complete a trail (Lezak, 1995; Reitan & Wolfson, 1993).

Initially, interpretation of the test rested on the assumption that the difference in completion time between TMT-B and TMT-A reflected the additional cognitive control required to switch between sequential numbers and letters, a process generally referred to as executive control. TMT-A was assumed to provide a baseline for motor and visual control and speed, against which to compare the time cost of executive control for each individual. In clinical practice, in addition to the completion times of TMT-A and TMT-B, two derived scores are often used for interpretive purposes: the B-A difference, and the B/A ratio. These derived scores are calculated to assess relative performance for TMT-B and TMT-A, providing information somewhat independent of motor speed and visual scanning speed (Corrigan & Hinkeldey, 1987; Heaton, Nelson, Thompson, Burks, & Franklin, 1985; Lamberty, Putnam, Chatel, Bieliauskas, & Adams, 1994). Slowed performance on TMT-B relative to TMT-A indicates cognitive impairment, specified by some as impaired ability to execute and modify a plan of action (Golden, 1981) or general frontal lobe dysfunction (Ameiva, Lafont, Auriacombe, Rainville, Orgogozo, Dartigues, & Fabrigoule, 1998; Pontius & Yudowitz, 1980).

Recently, however, several studies have questioned the assumption that TMT-B differs from TMT-A only in cognitive demand. Several researchers have demonstrated that the two parts of the test differ with respect to length of the completed trails and degree of interference in the visual scanning element of the task. Specifically, the TMT-B trail is longer than that of TMT-A, and this increased length increases the time required to complete TMT-B relative to TMT-A, independent of the sequential alternation factor (Arnett & Labowitz, 1995; Crowe, 1998; Gaudino, Geisler, & Squires, 1995; Rossini & Karl, 1994; Vickers, Vincent, & Medvedev, 1996). Furthermore, visual scanning for TMT-B is more difficult because more interfering circles are present between consecutive targets for TMT-B than for TMT-A (Crowe, 1998; Gaudino et al., 1995). Thus, both motor control and visual selection factors influence the difference between TMT-B and TMT-A completion times.

The evidence for motor and perceptual differences between TMT-B and TMT-A is clear and direct. Conversely, the evidence supporting the original assumption that TMT-B measures cognitive control is largely indirect. In the studies of Gaudino et al. (1995) and Crowe (1998), alternating between numbers and letters increased time to complete a trail, independent of trail length or visual complexity, suggesting that sequence alternation places more demand on the relevant processes. Secondly, factor analytic studies indicate that TMT-B loads on an attention factor (O'Donnell, MacGregor, Dabrowski, Oestreicher, & Romero, 1994) and populations such as those with frontal lobe lesions or traumatic brain injury perform more poorly on the TMT-B (Corrigan & Hinkeldey, 1987; Pontius & Yudowitz, 1980; Reitan, 1971; Stuss et al., 1989). These same populations are hindered by interference on other measures such as the Wisconson Card Sort Task or the Brown-Peterson (Consonant Trigram) task, providing converging evidence of attentional impairment.

Given the widespread use of the TMT as a screening measure for executive dysfunction (Lezak, 1995), it seems prudent to directly test the assumption that cognitive control is captured in TMT-B performance. Furthermore, it remains unclear to what degree the commonly-used derived scores (B-A and B/A) provide information about cognitive control relative to motor and perceptual factors. The purpose of this study is to examine this question more directly, by comparing TMT-B performance with performance in an experimental task that involves switching between different cognitive tasks, known as the set-switching paradigm (Allport, Styles, & Hsieh, 1994; Mayr & Keele, in press; Meiran, 1996; Rogers & Monsell, 1995).

## SET-SWITCHING

Predictable task alternation, such as that in the TMT-B, has been studied in experimental psychology since 1927, when Jersild had participants alternate between mental arithmetic (subtract 3 from each given number) and word generation (give the antonym for each word). More recent set-switching investigation focuses on determining task contexts that require executive control, as measured by cost to switch between tasks (e.g., Allport et al., 1994; Meiran, 1996; Rogers & Monsell, 1995). The cost to switch between tasks is measured relative to consecutive same-task trials, allowing measurement of the time required to switch tasks separate from the time required to complete each task in the absence of switching. Switch cost is reliably observed whenever a stimulus is associated with more than one task (e.g., name the ink color or read the word for Stroop color-word stimuli). Such an ambiguous stimulus environment requires participants to mentally keep track of the to-be-completed task, and it is this mental discrimination that appears to require executive control, rather than switching between tasks per se (Allport et al., 1994; Meiran, 1996; Rogers & Monsell, 1995; Spector & Biederman, 1976). Switch costs are only slightly reduced with extensive practice or with more preparation time before a switch, both of which significantly reduce overall reaction times (RTs) for the individual tasks (Meiran, 1996; Rogers & Monsell, 1995). The latter observations provide support for the contention that switch costs reflect executive control processes rather than task-specific processes.

Most research on set-switching has used alternation across two tasks, as in the TMT-B. Recently, Mayr and Keele (in press) hypothesized that two-task alternation reflects a special situation of set-switching rather than a pure measure of the cost to shift attention to a different goal. Specifically, they argued that shifting from one task-set to another would require inhibitory control of the currently irrelevant task-set, similar to distractor inhibition in selective attention (Houghton & Tipper, 1994) or to self-inhibition observed in sequential tasks (Arbuthnott, 1996). They refer to this inhibitory process as 'backward inhibition' but we prefer the label 'task-set inhibition'. If switching between tasks involves inhibition of no-longer-relevant task-sets, then the switch cost observed in two-task situations could reflect either the cost of shifting attention to a new task-set, or the cost of dealing with residual inhibition associated with a recently-suppressed task-set (or both).

To test this hypothesis, Mayr and Keele (in press) had participants perform three different tasks in sequence and compared performance for task alternation (i.e., AB**A** arrangement of tasks) with performance across three-trial series without alternation (i.e., CB**A** arrangement of tasks). Consistent with the hypothesis of task-set inhibition, they observed slower response for the third trial in an alternation series than for the third trial in a three-task series. As for set-switching in general, task-set inhibition was not observed when the task was unambiguously indicated by the stimulus display (Mayr & Keele, in press, Experiment 4), indicating that the effect reflects executive control processes. Task-set inhibition can therefore provide a relatively clear indication of executive control involved in switching flexibly between tasks. To the degree that TMT-B also measures this ability, we would expect TMT-B times to correlate with task-set inhibition.

## RATIONALE AND PREDICTIONS

To assess whether TMT-B performance correlates with set-switching, we had normal participants complete both the TMT and a version of Mayr and Keele's (in press) set-switching task. The set-switching task involved three different tasks, sequenced to enable separate measurement of the time required to shift between tasks with and without task alternation. If TMT-B is observed to reflect set-switching cost, this design will also allow an assessment of whether this cost is associated more with the process of switching attention to a different task (i.e., a move from task 1 to task 2), or with the processes involved in returning to a previously abandoned task (i.e., the move BACK to task 1 following completion of task 2).

The set-switching task provides a measure of the executive control involved in managing performance of more than one task at a time, while minimizing the elements of motor control and visual scanning that are present in the TMT. The tasks used for set-switching are simple cognitive judgments (e.g., odd/even categorization) or operations (e.g., adding 3 to a series of numbers). Responses are vocal or simple discrete manual responses such as pressing a button. Thus the element of manual control and coordination that influences performance on the TMT is reduced considerably. Similarly, stimuli for each trial of a set-switching task are presented discretely, minimizing the need for extensive visual scanning as in the TMT. Set-switching stimuli do require selection of one feature or character from among several options, maintaining the element of selection among potential distractors. However, the influence of this within-trial selection cost on performance can be minimized by examining performance on set-switching trials relative to performance on consecutive trials of the same task which also contain the within-trial complexity. Thus if TMT-B or either of the derived scores (B-A or B/A) measures executive control, this should be indicated by a positive correlation with switch cost or task-set inhibition, while controlling for the influence of no-switch RT. Conversely, if TMT-B simply measures the added demands of longer trail length and visual scanning interference, then no correlation would be predicted.

## METHOD

### Participants

Thirty-four participants (22 women; 65% of the sample) took part in the study. They ranged in age from 18 to 48 years ($M$ = 24.9 years; $SD$ = 8.9). Participants spoke English as their first language, reported normal or corrected-to-normal vision, and had no history of brain injury or illness (assessed with a single question). Participants were not screened for psychiatric, attentional, or learning difficulties. All participants were recruited from undergraduate psychology classes and received course credit in exchange for participation. The study took approximately 40 minutes for each participant.

### Set-Switching Stimuli and Design

For the set-switching task participants judged (1) whether a presented digit was odd or even, (2) a presented letter was a vowel or a consonant, or (3) a presented symbol was used primarily in math or text contexts. Responses were given vocally. Six characters for each task were used as stimuli. Digits were 2, 4, 6 (even) or 3, 5, 7 (odd); letters were G, M, R (consonants) or A, E, U (vowels), and symbols were ?, !, & (text) or +, <, = (math). For each trial, one of each character-type (i.e., symbol, digit, and letter) was included in the display, arranged in a column in the centre of the computer screen. For each trial, the character from each set and the position of each character type in the array (i.e., top, middle, or bottom character) were determined randomly.

The switch condition was manipulated by sequencing the order of tasks across each 5-trial series. The first two trials in the sequence involved the same task (trial 2 = no-switch condition), the third trial was one of the other tasks (1-switch condition), the fourth trial was the remaining task (2-switch condition), and the fifth trial was a return to the task of trial three (alternating-switch condition). For example, participants would judge (1) the letter, (2) the letter, (3) the digit, (4) the symbol, and (5) the digit, across five consecutive trials. The first trial in the series could be a no-switch, a 2-switch, or an alternating-switch trial, randomly determined by the tasks in trials 4 and 5 of the previous series. There are six possible arrangements of the tasks in this sequence (i.e., ddlsl, ddsls, lldsd, llsds, ssdld, ssldl, where d is digit, l is letter, and s is symbol judgment), for a total of 30 trials in which each switch condition is tested twice for each task. This 30-trial set was repeated 4 times throughout the experiment, with each 30 trials presented in a separate block. For each block, the order of each 5-trial series was randomly determined. This organization meant that the order of specific tasks was not predictable, so each trial was preceded by a cue question (i.e., Odd or Even?, Vowel or Consonant? or Math or Text?) that indicated which judgment was required. The design of the set-switching task was 3 (task: digit, letter, or symbol judgment) × 4 (switch condition: no-switch, 1-switch, 2-switch, alternating-switch conditions). All factors were tested within participants.

**Apparatus and Procedure**

The order of tasks (Trail Making Test or set-switching task) was counterbalanced across participants. The Trail Making Test was administered in the standardized manner (Lezak, 1995) with Part A preceding Part B, and correction of errors included in the completion times. Using the computer software clock as a timing device[1] allowed TMT completion times for each trail to be recorded to the nearest 100 ms.

Stimuli for the set-switching task were presented on an Intel 80286-based computer connected to a monitor that displayed white characters against a dark background. The task for each trial was cued 500 milliseconds (ms) prior to the appearance of the 3-character stimulus. Cue questions were presented horizontally at the horizontal centre and slightly above the vertical centre of the screen. Stimulus characters were presented in a column, with the top character centered on the screen. Characters were about 6 mm × 4 mm. Participants wore a lapel microphone that triggered a relay switch connected to the computer's serial port. The voice-activated relay provided the stop-signal for a software clock accurate to 1 ms.

Participants were tested individually in a small room with the experimenter present. The sequence of events for each trial was as follows: The cue question appeared and remained on screen for 500 ms, and then was joined by the 3-character stimulus array. The cue and stimulus remained on screen until the participant made a vocal response. Fifty ms after the response, the cue for the next trial appeared on screen. This combination of short response-cue interval (50 ms), and longer cue-stimulus interval (500 ms) provides participants with an opportunity to prepare for the upcoming task-set between trials (Mayr & Keele, in press; Rogers & Monsell, 1995). Errors and verifications of correct responses were entered by the experimenter.

Participants were initially given 45 training and practice trials to familiarize them with the set-switching tasks. For each type of judgment, five trials were presented with the cue question (e.g., Math or Text?), and only the relevant character (e.g., &). Following this, five trials of the same task were presented with the 3-character display. Each task was introduced in this manner, beginning with the symbol task and ending with the digit task. Following this single-task introduction, participants received 15 mixed-task practice trials with tasks and characters displayed in the same manner as for the experimental trials. Participants were instructed to respond to each trial as quickly and as accurately as possible.

The set-switching task was presented in 4 blocks of 30 trials, with a 1 minute break between blocks. Each block included the six unique orders of task condition across the 5-trial switch condition sequence. All 30 trials in a block used the same timing, and no participant reported noticing any regularity in the order of task switches.

## RESULTS

**Trail Making Test**

Mean performance on the TMT was within the normal range according to published norms, and was very similar to performance on a local norming study of 341 participants (Crossley et al., 1998). Means were 19.2 secs ($SD = 5.5$) for TMT-A, and 47.6 secs ($SD = 16.5$) for TMT-B. Using Heaton, Grant, and Matthews' (1992) demographically-corrected norms, the average T-scores for our sample were 59 ($SD = 10$) for TMT-A and 57 ($SD = 12$) for TMT-B. Completion times on TMT-A were faster for women, $t(32) = 2.25$, $SE = 1.87$, $p = .032$ ($M = 17.7$ secs and 21.9 secs for women and men, respectively). This sex difference is not typically observed clinically, but was previously reported for TMT performance in a university population (Gaudino et al., 1995).

We calculated two derived TMT scores that are commonly used in clinical interpretation, the B-A difference and the B/A ratio. For our sample, the mean difference score was 28.4 ($SD = 15.2$) and ranged from 5.8 to 72.9. The ratio score ranged from 1.4 to 7.4, with a mean of 2.6 ($SD = 1.1$). We used these derived scores to examine the relationships between performance on TMT-B and performance on the set-switching task.

[1] The computer was used as a stopwatch, with the software clock started by pressing the spacebar when the participant was instructed to begin, and stopped by pressing the spacebar a second time when the participant was completed. This timing routine was coded within the same program that presented the set-switching task. The experimenter administered the paper-and-pencil version of the TMT using the typical demonstrations and vocal instructions.

**Set-Switching Task**

Mean correct RTs for each switch condition by task are shown in Figure 1. These RTs were analyzed using a 4 (switch condition) × 3 (task) repeated measures analysis of variance (ANOVA). This analysis indicated main effects of both task, $F(2, 66) = 8.66$, $MSe = 115{,}504$, $p < .001$, and switch condition, $F(3, 99) = 7.23$, $MSe = 60{,}317$, $p < .001$. The interaction was not significant ($F < 1$). Post-hoc analyses using Tukey's honestly significant difference (HSD) indicated that the task effect resulted from slower RTs for letter judgment (mean = 1323 ms) relative to digit and symbol judgment (means of 1183 ms and 1192 ms respectively), $HSD = 99$.

The main effect of switch condition reflected longer RTs in the alternating-switch condition (mean = 1318 ms) relative to all other conditions (means of 1178 ms, 1180 ms, and 1220 ms for the no-switch, 1-switch, and 2-switch conditions respectively), $HSD = 83$. Neither the 1-switch nor 2-switch conditions differed significantly from no-switch RTs.[2] The difference between switch conditions in this study was the relationship between the task on the current trial and the task on either the previous trial (no-switch and 1-switch conditions) or the task on two previous trials (2-switch and alternating-switch conditions). As the switch effect did not interact with task, this result is attributable to a global level of task-set rather than specific representations of a particular task, stimulus, or response (see Mayr & Keele, in press for similar findings with a set of perceptual selection tasks). Thus, the significant cost for the alternating-switch condition relative to the other switch conditions can be interpreted as a measure of executive control processes.

**Inter-Task Correlations**

We initially examined correlations between both parts of the TMT and RTs for all switch conditions. We predicted that any correlations between set switching and the TMT would be positive, and therefore one-tailed tests of significance were used. These correlations are presented in the top panel of Table 1. As can be seen, performance in each task correlated significantly with the other measures of the same task, as would be expected. More interestingly, performance on TMT-B correlated significantly with performance for the no-switch condition ($r = .35$, $p = .021$) and the alternating-switch condition ($r = .36$, $p = .018$). The correlation between TMT-B and the 2-switch condition was also marginally significant ($r = .27$, $p = .058$), but TMT-B performance did not correlate with the 1-switch condition ($p > .1$).

To isolate the similarities between these tasks more clearly, we then examined the correlations between the TMT derived scores and the switch conditions, controlling for RT on the no-switch condition. This analysis was conducted (1) to reduce the influence of general and strategic speed factors on both sets of values, and (2) to reduce the influence of the visual complexity factors present in both tasks. For the TMT, visual search is necessary for both parts A and B (although visual interference is greater for Part B, Gaudino et al., 1995), and for the set-switching task visual selection is necessary to isolate the task-relevant character from the 3-character display. For the set-switching task, this visual complexity was present equally for the no-switch condition and the alternating-switch condition, so partialling out the no-switch RT controls for both the overall speed and visual complexity factors for this task. Furthermore, this analysis should indicate which of the derived scores provides better information about cognitive set-switching ability as measured by the TMT.

The difference score did not correlate with any condition in the partial correlation analysis (see the lower panel of Table 1), suggesting that the significant correlations observed with the set-switching task were mostly attributable to factors associated with the no-switch condition, such as processing speed and visual selection. Thus, it seems likely that this derived score mostly provides a measure of the visual scanning and selection factors recently shown to differentiate TMT-B and TMT-A. Conversely, the TMT ratio score correlated significantly with the

[2] See Arbuthnott & Frank (2000) for more detailed discussion of the set-switching results.

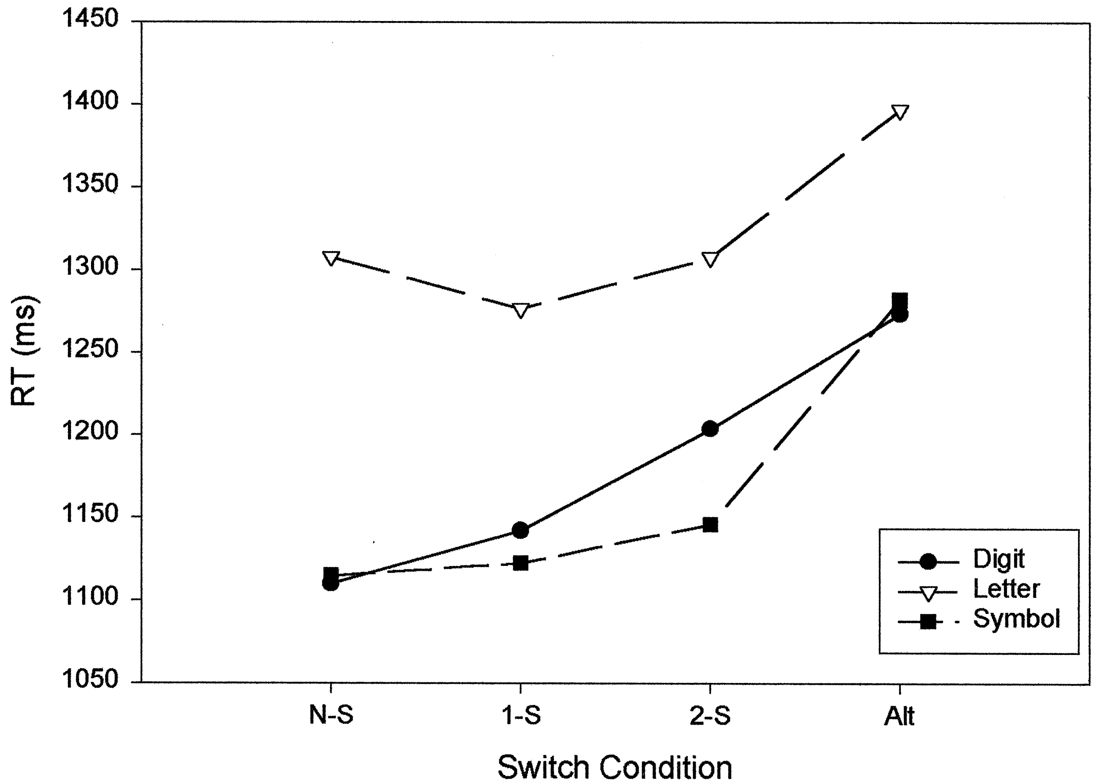


Fig. 1. Reaction Times by Switch Condition and Task.
*Note*. N-S = no-switch; 1-S = 1-switch; 2-S = 2-switch; Alt = alternating-switch.

Table 1. Intertask correlations, $r(34)$.

| | TMT-A | TMT-B | B-A | B/A | NS-RT | 1S-RT | 2S-RT |
|---|---|---|---|---|---|---|---|
| TMT-A | | | | | | | |
| TMT-B | .39* | | | | | | |
| B-A | .06 | .94** | | | | | |
| B/A | –.34* | .67** | .85** | | | | |
| NS-RT | .05 | .35* | .36* | .29* | | | |
| 1S-RT | –.13 | .16 | .22 | .30* | .72** | | |
| 2S-RT | .08 | .27 | .27 | .30* | .77** | .88** | |
| ALT-RT | .01 | .36* | .39* | .45* | .75** | .87** | .92** |

Correlations with NS-RT partialled out, $r(31)$

| | 1S-RT | 2S-RT | ALT-RT |
|---|---|---|---|
| B-A | –.07 | –.02 | .19 |
| B/A | .14 | .13 | .37* |

*Note*. NS = no-switch, 1S =1-switch, 2S = 2-switch, ALT = alternating-switch.
* p < .05, one-tailed; ** p < .001, one-tailed.

alternating-switch condition RT ($r$ = .37, $p$ = .016). Partial correlations of the ratio score with 1-switch and 2-switch conditions were not significant ($p$'s > .2), suggesting that the process of shifting attention from one task to another does not strongly contribute to longer times to perform different tasks sequentially. Rather, the cost associated with performing different tasks in succession appears to be more strongly associated with returning to a task-set that has recently been abandoned (i.e., suppressed). However, whatever the processing locus of set-switching cost, it appears that the TMT ratio score provides a better indicator of this ability than the difference score.

To further explore the nature of the correlation between the TMT ratio score and set-switching performance, we divided participants into three groups based on their ratio score, those with ratios < 2 ($N$ = 10), those with ratios between 2 and 3 ($N$ = 15) and those with ratios > 3 ($N$ = 9; Lamberty et al., 1994). We then conducted a 3 (TMT ratio group) × 4 (switch condition) mixed factor ANOVA. This analysis indicated main effects of both TMT ratio group, $F(2, 31) = 4.77$, $MSe = 282{,}533$, $p = .016$, and of switch condition, $F(3, 93) = 8.19$, $MSe = 19{,}925$, $p < .001$. The interaction was not significant. As can be seen in Figure 2, the alternating-switch condition was slowest for all groups ($HSD$ for the switch condition comparison = 91), and the RT for all conditions increased with increasing TMT ratio score. The main effect of ratio group indicates that participants with a low TMT-B to TMT-A ratio were faster for all switch conditions relative to those with ratios over 3 ($HSD$ = 318). This analysis indicates that the B/A ratio score predicts performance in a non-motor task that involves switching among task-sets. This result thus provides further support for the clinical practice of interpreting executive difficulty using the ratio score, particularly for consider-

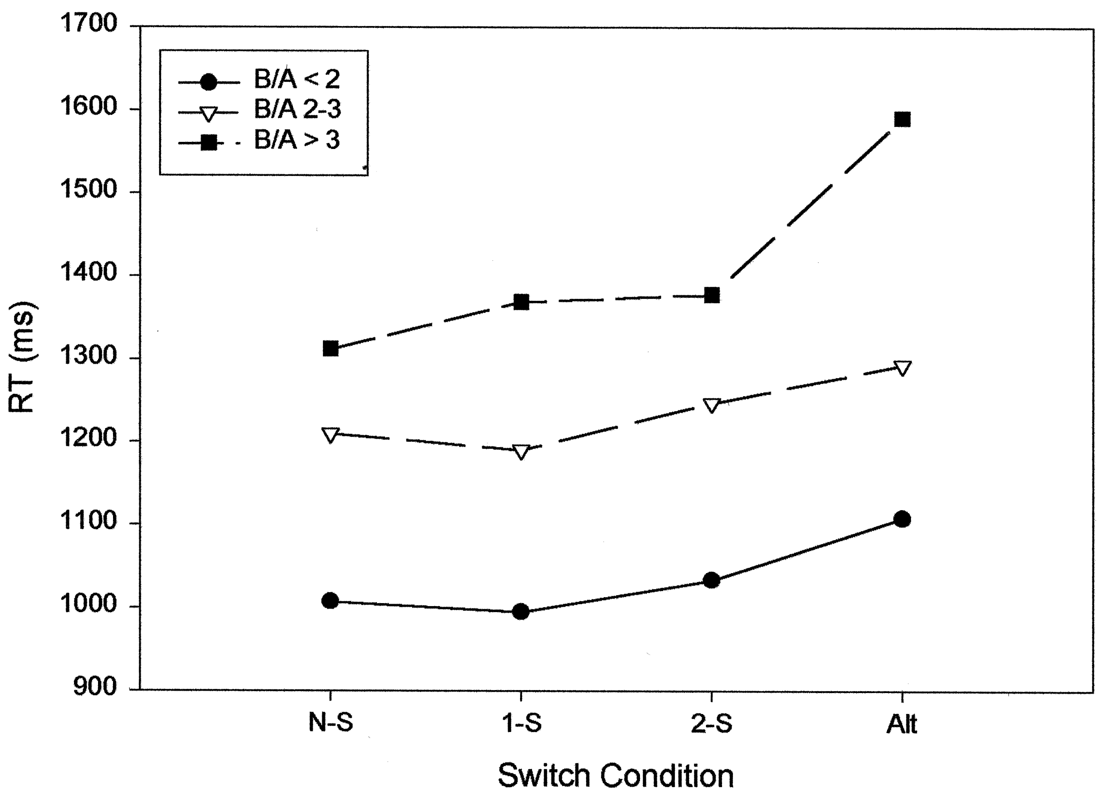


Fig. 2. Switch Conditions by TMT B/A Ratio Category.

ing ratios of >3 to indicate set-switching impairment.

## DISCUSSION

To summarize, this study found significant set-switching cost relative to performance on consecutive same-task trials, but only for switches that alternated between two tasks. Alternating-task performance was positiviely correlated with TMT-B performance, especially with the B/A ratio score. Overall, the correlational analyses indicate (1) that the performance of TMT-B relative to TMT-A does reflect attentional control processes necessary to manage rapid alternation of two tasks, and (2) that this control may be largely related to the efficiency of resolving suppression of a previously-abandoned task.

The set-switching task in this study replicated the findings of Mayr and Keele (in press) using categorization judgments rather than perceptual selection tasks. The use of vocal rather than manual responses also removed any potential for interference between responses for the different task-sets, as is present using keypress responses (Rogers & Monsell, 1995). The significant task-set inhibition effect observed in this study is therefore clearly attributable to cognitive task-set management, and not to control of perceptual and motor processes. This conceptual replication provides support for the contention that task-set inhibition reflects an executive control process that operates in situations of flexible switching between task-sets.

Mayr and Keele (in press) hypothesized that the inhibition of previous task-sets is one of the executive control processes necessary to manage task switching (see also Baddeley, Emslie, Kolodny, & Duncan, 1998). Based on this hypothesis, they predicted that it would take longer to alternate between tasks than to switch tasks without alternation. Specifically, they suggested that if each task-set is suppressed when a switch is required, then a return to the original task would require additional processing time to deal with the task-set inhibition. Conversely, a switch to a less recently abandoned task would not encounter such inhibition. The results of this study were consistent with this prediction: RTs were slower for alternating-switch trials than they were for either consecutive same-task judgments, or for trials that involved switching between different tasks on two or three consecutive trials. Furthermore, the absence of switch cost for non-alternating trials (i.e., 1-switch and 2-switch conditions) suggests that set-switching costs previously observed for switches between two tasks (e.g., Allport et al., 1994; Rogers & Monsell, 1995) may be largely attributable to residual inhibition processes, rather than to the cost of switching task-set per se.

The task-set inhibition effect thus provided the clearest evidence of cognitive control in this study. Therefore, the correlation between the alternating-switch condition and the TMT is the most relevant for determining whether TMT-B assesses cognitive control processes. TMT-B times and both derived scores were significantly associated with RTs for this condition. Most importantly, when the influence of times for the no-switch trials were controlled, the B/A ratio score still showed significant correlation with the alternating-switch condition. This provides strong evidence that relative performance on TMT-B and TMT-A provides a measure of cognitive control processes, as is commonly assumed in clinical practice. Thus, despite the recent evidence that TMT-B times differ from those of TMT-A in perceputal and motor control factors, the results of this study indicate that the ratio measure is useful to assess cognitive control processes. In clinical populations, the ratio score also controls for other factors known to influence TMT performance, such as age and education (Lamberty et al., 1994), and thus this derived measure may be the most useful for screening applications of the TMT.

Although these results are clear and straightforward, the study has several limitations, especially for application to clinical populations. First, the participants of the study were all normal individuals within a homogeneous population (i.e., university students). Second, the study employed only 34 participants and 65% of the sample was female. Further research is thus necessary to replicate these results, and to extend the comparison of TMT and set-switching performance to clinical populations. As a first step in this process, a group of individuals who have suffered traumatic brain injury (TBI) are currently being tested in our lab. On the basis of the present results, we predict that the TBI group will show larger B/A ratio scores and larger alternating-switch cost than normal participants, resulting in a correlation coefficient between the two tasks that is similar to the present observation. It is also possible that the TBI group will show significant cost for non-alternating switch trials as well, which may indicate that there are additive effects associated with these different task-switch conditions.

The purpose of this study was to directly assess the validity of the assumption that TMT-B differs from TMT-A in cognitive demand, especially that of executive control necessary to manage switches between two well-learned sequences. This was accomplished by comparing performance in the TMT with an experimental task previously shown to reflect ''top-down'' or executive control processes. This comparison clearly indicated that TMT-B performance is associated with set-switching cost, and that the B/A ratio score may provide the best indicator of executive control function. Thus, the assumption underlying clinical interpretation of the TMT appears to be valid, and the test can continue to be confidently used as an efficient means to assess executive function.

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