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Effects of Age and Dementia on the Trail Making Test*

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ABSTRACT

Trail Making Test (TMT) performance was investigated in 765 elderly volunteers (age range 60 to 96 years), 58 of whom met DSM-III-R criteria for dementia and 40 dementia ''suspects,'' who showed mild changes in one or two cognitive domains. Cross-sectional analyses of the 667 nondemented participants, revealed significant age effects in completion times for both Parts A and B. Prevalence of errors increased with age on Part B, but not on Part A. Two-year longitudinal changes were examined in a subset of the nondemented sample (n = 385). Significant slowing was found for Part B, but not for Part A, with older age groups showing the greatest change. Error rates did not increase. Dementia status accounted for a significant proportion of the variance in completion times after accounting for age, education, and gender. Receiver operating characteristic analyses suggest that the TMT may be useful in screening for cognitive dysfunction.

The Trail Making Test (TMT) of the Halstead-Reitan Battery (e.g., Reitan, 1992) appears to be sensitive to the cognitive changes associated with aging, head trauma, and diseases affecting cerebral functioning. The test consists of two parts. Part A requires the participant to draw lines connecting 25 consecutively numbered circles that are arranged in a random visual array on a single sheet of paper. Part B requires the participant to connect a similar array of circles containing numbers and letters. The sequence must follow alphanumeric order. Participants are instructed to complete each part as fast as they can. As such, both parts of the TMT require motor speed and coordination, attention, and visual scanning. The alphanumeric alternation on Part B likely also requires the involvement of cognitive processes commonly referred to as set shifting, or attentional, mental, or cognitive flexibility (see Lezak, 1983; Reitan & Wolfson, 1993; Spreen & Strauss, 1991).

The TMT is a frequently used clinical tool and a computer-administered test resembling the TMT was developed for experimental use (Salthouse & Fristoe, 1995).

Age-associated performance decrements on the TMT are well documented (e.g., Bak & Greene, 1980; Davies, 1968; Ivnik, Malec, Smith, Tangalos, & Peterson, 1996; van Gorp, Satz, & Mitrushima, 1990; Wiederholt et al., 1993), but there have been no reports of longitudinal change. Many early studies reported the percentage of participants classified as brain damaged by age group, but did not analyze age effects on raw time scores, or even present the raw times. For example, Davies (1968) found that approximately 90% of normal participants in their 70s would be classified as ''brain dam-

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aged'' according to Reitan's (1955) cutoff scores. Later studies have had small sample sizes in the older age groups (e.g., $n = 15$ each in the 50-to-62 and 67-to-82-year-old groups; Bak & Greene, 1980), or divided samples into uneven, or discontinuous, age intervals (e.g., 20–39, 40–59, and 60–69; Bornstein, 1985). A recent report of age effects on the TMT included only Part B, and the large community-dwelling sample included dementia cases (Wiederholt et al., 1993). Perhaps the best data for normal elderly are provided by the Mayo's Older American Normative Studies, but the data published for the TMT do not extend above age 82 (Ivnik et al., 1996). Rarely has the issue of error rate been addressed.

Further investigation of age effects on TMT completion times and error rate is warranted by recent reports that TMT Part B is useful in discriminating dementia from normal aging. Cahn et al. (1995) found Part B to be among the variables entering a logistic regression model discriminating between demented and nondemented elderly individuals. Similarly, Part B was also among the variables entering a multiple logistic regression equation predicting new dementia cases (Dal Forno, Corrada, Resnick, & Kawas, 1995). Thus, the TMT may be useful in predicting dementia.

The goals of the present study were (1) to describe cross-sectional age effects on the TMT in a large sample aged 60 to 93 years, (2) to describe two-year longitudinal changes on the TMT in a subset of this sample, and (3) to examine the utility of the TMT in discriminating cognitive dysfunction from normal aging.

METHOD

Participants

The Baltimore Longitudinal Study of Aging (BLSA) consists of a community-dwelling, generally healthy group of volunteers who have agreed to return for medical and psychological testing every other year (Shock et al., 1984). The sample has been recruited continuously since 1958, and the majority are White men; working, or retired from scientific, professional, or managerial positions; graduated from high school (97%) or college (71%); and married. The only criterion for inclusion in the present study was that participants were 60 years or older at the last visit at which the Trail Making Test was administered. Table 1 describes the characteristics of the sample of 765 eligible participants as a function of dementia status.

Procedure

As part of the biennial BLSA assessment, participants received a battery of neuropsychological tests, including the Trail Making Test (TMT). Both

Table 1. Descriptive Characteristics of BLSA Participants by Dementia Status.

	Dementia Status					
Variable	Nondemented (n = 667)		Suspects (n = 40)		Dementia (n = 58)	
Age (years)	*M*	(*SD*)	*M*	(*SD*)	*M*	(*SD*)
Education (years)	74.4	(8.2)	82.4	(6.4)	82.0	(6.7)
MMSE (total)	16.0	(2.9)	16.0	(3.2)	16.2	(2.9)
BMS (errors)	28.6	(1.6)	26.6	(2.4)	22.9	(5.4)
Trail Making Test	1.3	(1.8)	4.3	(3.1)	8.8	(5.9)
Part A (time, s)						
Part B (time, s)	40.6	(16.4)	63.4	(28.1)	94.7	(62.4)
	106.0	(53.4)	181.4	(73.9)	212.0	(73.8)
% Women	37		31		44	

Note. Dementia diagnosis by DSM-III-R criteria. Suspects show mild impairment in one or two cognitive domains with no evidence of functional impairment. All values are means and standard deviations, except where noted. MMSE = Mini-Mental State Examination; BMS = Blessed Mental Status Test.

Parts (A and B) of the TMT were administered in a standardized manner similar to that described in the TMT manual (Reitan, 1992). Times to complete Parts A and B were recorded, and a maximum of 300 s was allowed for each Part. Errors in sequence were pointed out by the examiner as they occurred so that the participant could correct the sequence before continuing. Whether the participant completed each Part without making an error was also recorded (0 = no errors, 1 = one or more errors). Participants who were unable to complete the sample problem successfully after multiple attempts and reiterations of the instructions were assigned the maximum time score of 300 s and an error score of 1 for that Part.

All BLSA participants aged 70 years and older are seen by a neurologist for a clinical evaluation. In addition, neurological evaluations are scheduled for any younger participant meeting any of the following criteria: (1) scoring 27 or lower on the Mini-Mental State Exam (MMSE; Folstein, Folstein, & McHugh, 1975); (2) scoring 3 or more errors on the Blessed Mental Status exam (BMS; Tomlinson, Blessed, & Roth, 1968); or (3) showing a change of 3 or more points between two BLSA visits on either of these screening measures. The neurologist completes a standard form documenting the presence of any abnormal signs, and also indicates an overall diagnostic impression (cognitively normal, suspect for early dementia, or dementia) based on the information obtained from the evaluation, independent of neuropsychological performance.

Using the information gathered from the longitudinal neuropsychological assessments, and neurological examinations, where available, all participants were conferenced and classified as either (1) cognitively normal (nondemented; $n = 667$); (2) normal, but with mild cognitive impairment in one or two cognitive domains (suggesting the possibility of early dementia), but no evidence of social or functional loss, (''suspects''; $n = 40$); or (3) demented according to DSM-III-R criteria for dementia (APA, 1987) ($n = 58$). Of the 58 participants with dementia, 39 met criteria for possible ($n = 5$), probable ($n = 24$), or definite ($n = 6$) Alzheimer's disease (AD) (McKhann et al., 1984) , or were considered ''consistent with AD'' ($n = 4$). This last designation was assigned when clinical presentation and history were consistent with AD, but laboratory tests were unavailable. Of the remaining dementia cases, 10 appeared to have a mixed dementia due to AD and cerebrovascular disease, 4 had Parkinson's disease with dementia, and 5 had an unspecified dementia. All data from individuals classified as suspects and demented were from visits dated concurrent with, or after, the onset of their symptoms.

It should be noted that poor performance on the TMT alone was not sufficient for classification as a suspect for dementia. Because the TMT is sensitive to subtle cognitive dysfunction, poor performance on additional cognitive measures was required for coding impairment in a specific cognitive domain.

Data Analysis

Effects of prior exposure to the TMT

We used the last available administration of the TMT test to maximize the number of older and demented persons in our analyses. Among nondemented participants, the number of prior exposures relative to the last available data point ranged from zero to 4 (n's = 197, 170, 144, 121, 35, respectively). In order to determine the importance of practice on performance, a one-way ANOVA was conducted on completion times for both Parts of the TMT with the number of prior exposures to the TMT as the grouping variable.

Cross-sectional analysis of age differences on the TMT

Examination of age differences on the TMT was restricted to the 667 nondemented participants. Multiple regression analyses were conducted to assess the effects of age, gender, and education on TMT completion times. The following variables were entered into the models in sequential order: age, age squared (to assess any quadratic relationship between age and TMT performance), years of education, and gender. To generate reference data for the TMT among the old and very old, means and standard deviations were calculated for each age group: 60s, 70s, 80s, and 90s. Finally, differences in the distribution of errors across the age groups were assessed by chi-square.

Longitudinal analysis of age changes on the TMT

Examination of age changes on the TMT was limited to a subset of 385 nondemented participants who had complete data for the TMT from two BLSA visits 2 years apart. Repeated measures ANOVAs were conducted on completion times for Parts A and B separately. In each analysis, age group at the first evaluation (three decades; 60–69, 70–79, and 80–89 years), and gender were the between-subjects factors, and time (Time 1 and Time 2 observations) was the within-subjects factor. The interaction effects were also assessed to determine whether greater changes occurred in TMT performance in the older age groups, or in one gender.

There were 105, 186, and 94 participants in the 60–69, 70–79, and 80–89 year-old age groups, respectively. The 90+ age group was excluded from these analyses because only 7 participants in this age range had longitudinal data. The change in error status across age groups and gender was assessed with chi-square.

Cross-sectional analyses of effects of dementia status on the TMT

In order to assess the effects of dementia on the TMT beyond the effects of age, the multiple regression analyses described above were repeated for all 765 participants, and the following variables entered in order: age, age squared, education, gender, dementia status (normal, suspect, and dementia), and a Dementia × Age interaction term. Differences in the distribution of errorless performances by dementia status were assessed by chi-square. Finally, a receiver operating characteristic (ROC) curve analysis was performed to determine the ability of the TMT to detect cognitive dysfunction. As a preliminary step, TMT performance and age group were entered simultaneously into a multiple logistic regression model. Times for Part A and Part B were both independently significant, although age group was not. Therefore, the ROC analyses were performed for Parts A and B independently using raw time scores. ROC curves were generated in which the nondemented elderly participants (n = 667) were discriminated from those classified as AD only (n = 39), any dementia (n = 58), and any cognitive dysfunction (suspects or any dementia, n = 98). The analyses investigating the relationship between dementia status and TMT were repeated for the 432 participants with a neurologist's diagnostic impression (344 cognitively normal, 57 suspects, and 31 demented) independent of TMT and other neuropsychological performance measures.

RESULTS

Effects of Prior Exposure to the TMT

There were more prior exposures in older participants, so the nondemented sample was stratified by age, and three ANOVAs were conducted separately on three age decade groups (90+ year-olds were excluded from this analysis due to several empty cells). The effect of prior exposure was significant only for TMT Part A in the 80-to-89-year-old age group (F(4,178) = 3.9, p < .01). The fastest subset of the 80-to-89-year-olds were those with three prior exposures, and they were not, on average, faster (43s) than the slowest subset of 70-to-79-year-olds (41s in those with two prior exposures). That is, age effects appeared to be more systematic and robust than practice effects. All other F values in these analyses were less than 1.0. Thus, the practice effects appear to be minimal and the last data point available was used for the cross-sectional analyses.

Cross-Sectional Age Differences on the TMT

The means and standard deviations for TMT times and mental status tests are listed by age group in Table 2. The older age groups performed significantly worse on the BMS (F(3, 663) = 2.9, p < .05) and the MMSE (F(3, 661) = 12.4, p < .001; 2 participants missing MMSE), and on both Part A (F(3, 663) = 42.8, p < .001) and Part B (F(3, 663) = 41.2, p < .001) of the TMT. However, the differences in mean scores across the age groups on the BMS and MMSE do not appear to be clinically meaningful (See Table 2). The age groups did not differ in gender distribution or years of education.

Results from the multiple regression analyses on time to complete the TMT are presented in Table 3. These results indicate that age was significantly associated with completion times for TMT Parts A and B. The lack of contribution of the age-squared term suggests that the relationship between age and completion time is best described as linear. After removing the influence of age, years of education was also significantly related to performance on both parts of the TMT. Less than 1% of the variance on Part A was explained by education, whereas on Part B, education accounted for an additional 3% of the variance beyond that associated with age. Gender accounted for a small, but statistically significant amount (< 1%) of additional variance in performance on Part B only, with men completing the test more quickly than women.

The percentages of participants who made errors in completing the TMT Part A across age groups 60s, 70s, 80s, and 90s were: 9.8%, 13.4%, 8.8%, and 5.3% respectively (χ^2 = 3.2, NS). The percentage of participants who made errors in completing TMT Part B across the age

Table 2. Means and Standard Deviations for Cognitive Measures and Education in Nondemented BLSA Participants by Age Decade.

	Age Group (years)			
	60–69 (M = 64.8) (n = 203)	70–79 (M = 74.2) (n = 262)	80–89 (M = 83.4) (n = 179)	90–96 (M = 91.5) (n = 23)
MMSE	29.0 (1.4)	28.7 (1.4)	28.2 (1.8)	27.8 (1.7)
BMS	1.2 (1.7)	1.2 (1.4)	1.6 (2.1)	1.7 (1.8)
TMT Part A (s)	32.1 (11.0)	40.7 (15.5)	48.6 (17.5)	52.1 (19.6)
TMT Part B (s)	81.2 (35.2)	103.3 (51.1)	132.1 (55.9)	153.0 (68.2)
Education	15.7 (2.8)	16.0 (3.0)	16.4 (2.9)	16.6 (2.9)
Range (years)	(8 to 20)	(8 to 20)	(7 to 20)	(12 to 20)

Note. The BLSA is a highly educated volunteer sample that is predominantly White. MMSE = Mini-Mental State Exam; BMS = Blessed Mental Status Exam; TMT = Trail Making Test.

groups were as follows: 34.5%, 39.0%, 48.2%, and 57.9% respectively (χ^2 = 9.4, p < .05). These results indicate an age-related increase in errors on Part B, but not on Part A.

Longitudinal age changes on the TMT

TMT completion times for the two time points are graphically represented in Figure 1. There was a significant effect of age group on TMT Part A completion times (F(2,379) = 40.2, p < .001). No additional main effects, or interactions were significant for Part A (all F's < 1.0). For TMT Part B completion times, there was a significant main effect of age group (F(2,379) = 28.25, p < .001), a significant main effect of time (F(1,379) = 34.2, p < .001), and a significant Age Group x Time interaction (F(2,379) = 9.0, p < .001). Thus, over a 2-year interval, Part A completion times remained stable, whereas a significant increase in Part B completion times was found. The Age Group x Time interaction effect on Part B reflects a greater performance decrement in the older age groups. No main effect or interaction effect involving gender was significant. Chi-square analyses found no difference in the longitudinal change in errors across age groups or gender on either part of the TMT. Thus, the performance decrement on Part B was measurable only in terms of speed.

Effects of Dementia Status on the TMT

Table 4 shows the results of the multiple regression analyses using all participants and dementia status as an additional covariate. These analyses indicate that dementia status accounts for a large portion of additional variance in TMT A and

Table 3. Regression Analyses for Nondemented Elderly Persons.

	Completion Times (s)			
	TMT Part A		TMT Part B	
	R^2 Change	R^2 Model	R^2 Change	R^2 Model
Age	.18**	.18	.17**	.17
Age Squared	.00	.18	.00	.17
Education	.01*	.19	.03**	.20
Gender	.00	.19	.01*	.21

Note. n = 667. *p < .05; **p < .001.

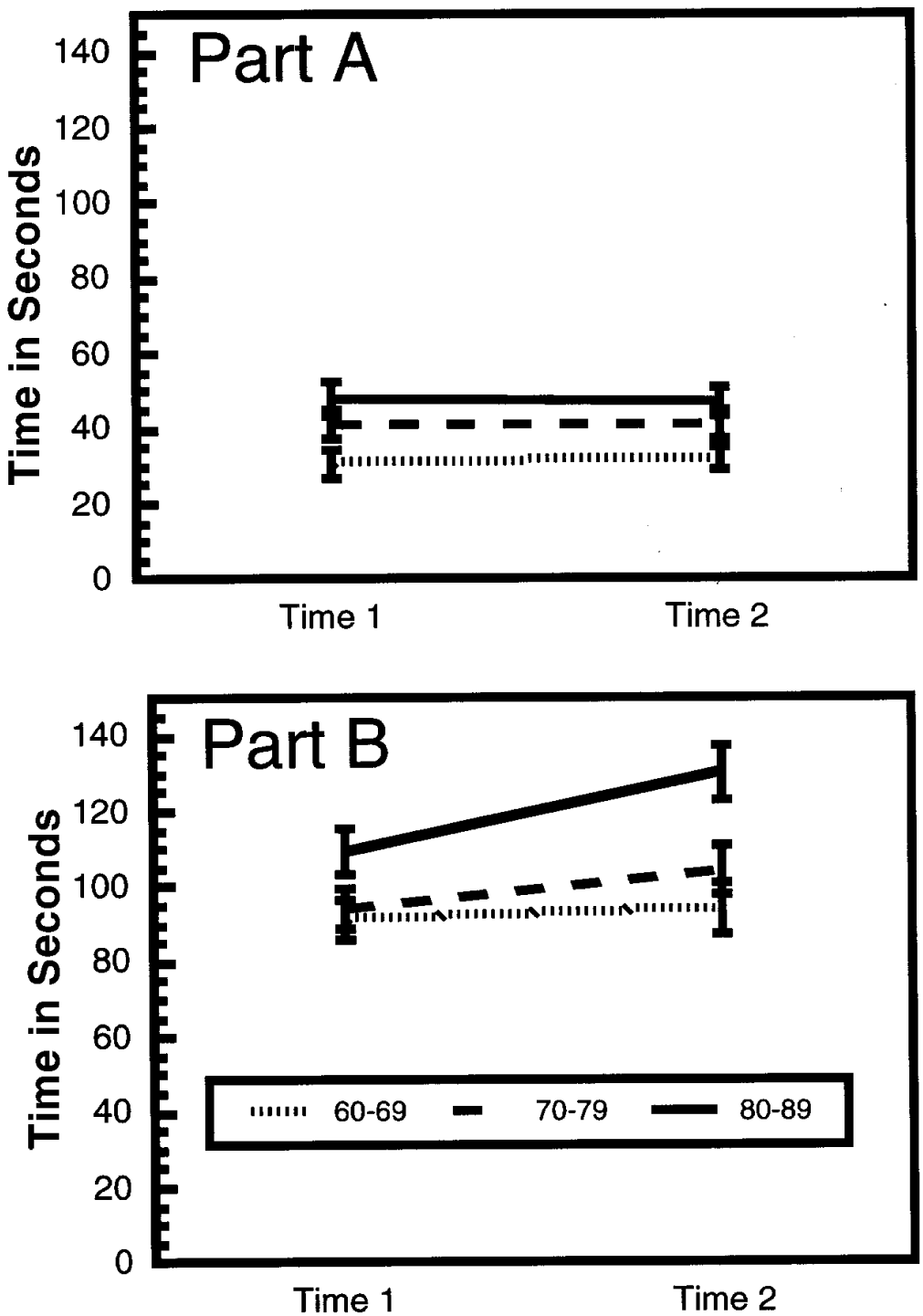

Fig. 1. Mean Trail Making Test (TMT) performance (+/– *SE*) in 385 nondemented participants tested on two occasions, 2 years apart, stratified by age group at initial assessment.

TMT B completion times after controlling for the effects of age, gender, and education. The interaction between age and dementia status accounted for a negligible amount of variability in TMT completion times, although it was statistically significant for Part B. Excluding the suspects from these analyses yielded virtually identical results. Likewise, the same effects were found in regressions with the 432 participants with a neurologist's independent diagnostic impression.

The percentages of participants who made errors in completing TMT Part A for the nondemented, suspect, and demented groups were: 10.2%, 15.4%, and 24.6%, respectively ($\chi^2 = 11.1$, $p < .01$). The percentage of participants who made errors in completing the TMT Part B for the nondemented, suspect, and demented groups were: 38.6%, 64.1%, and 76.8%, respectively ($\chi^2 = 38.3$, $p < .001$). In order to insure that the effects of dementia status on error production were not due to the age differences between these groups, logistic regressions were performed with age group and dementia status as covariates. After removing the effects of age, the effects of dementia remained significant for both Part A ($\chi^2 = 10.7$, $p < .01$) and Part B ($\chi^2 = 17.6$, $p < .001$). Thus, dementia status was significantly associated with the proportion of participants who made errors on both TMT Part A and Part B independent of age.

A summary of the ROC analyses can be found in Table 5. The area under the ROC curves ranged from.85 to.89. Both Parts A and B had cutoff scores that would provide a range of sensitivity and specificity values suitable for a variety of needs. The previously reported optimal dementia cutoff score of 172s on Part B (Cahn et al., 1995) resulted in the correct classification of 89.4% of the nondemented participants (specificity). This cutoff score correctly classified 63% of the participants with any cognitive dysfunction (i.e., suspect and demented participants combined, $n = 98$), 72% of the participants meeting criteria for dementia ($n = 58$), and 77% of the participants meeting criteria for dementia of the Alzheimer's type ($n = 39$).

Repeating these analyses on the 432 BLSA participants who had a neurologist's diagnosis (independent of any neuropsychological test results) replicated all significant effects in the multiple regression analyses on time, and chi-square analyses on error rates. A Part B dementia-cutoff of 172s correctly identified 83% of the nondemented participants, 56% of those thought to have any cognitive dysfunction by the neurologist (i.e., suspects and dementia combined, $n = 88$), and 67% of those thought to be demented ($n = 31$).

DISCUSSION

The findings in the large sample of nondemented elderly participants in the present study contributes to the existing literature regarding age effects on the TMT. Cross-sectional analyses revealed significant age effects on both

Table 4. Regression Analyses Results for All Participants.

	Completion Times (s)			
	TMT Part A		TMT Part B	
	R^2 Change	R^2 Model	R^2 Change	R^2 Model
Age	.16**	.16	.20**	.20
Age Squared	.01*	.17	.01*	.21
Education	.01*	.18	.03**	.23
Gender	.00	.18	.00	.23
Dementia	.18**	.36	.13**	.36
Dementia × Age	.00	.36	.01**	.37

Note. $n = 765$. *$p < .05$; **$p < .001$.

Table 5. Sample TMT Cutoff Scores From ROC Analyses and Corresponding Specificity and Sensitivity.

	% Specificity	% Sensitivity		
Cutoff Times (s)	Nondemented (n = 667)	AD Only (n = 39)	Any Dementia (n = 58)	Suspects + Any Dementia (n = 98)
TMT Part A				
< 300	100	7	5	13
< 150	100	13	10	7
< 100	99	38	34	25
< 50	78	87	82	75
< 25	11	97	96	97
< 15	0	100	100	100
TMT Part B				
< 300	99	31	31	26
< 250	97	33	34	29
< 200	93	59	51	45
< 150	83	79	74	70
< 100	58	97	94	80
< 50	5	100	100	100

Note. TMT = Trail Making Test; ROC = receiver operating characteristic; AD = Alzheimer's disease.

Part A and Part B time scores. An age-associated increase in error prevalence was seen for Part B, but not Part A. Two-year longitudinal changes were not found for Part A, whereas they were quite pronounced on Part B. Furthermore, there was a significant age group by time interaction for Part B time scores, wherein the older participants showed greater performance decrement over the 2-year interval than did the younger participants (see Figure 1).

These findings further illustrate the age-complexity effect, or the tendency for age effects to be more pronounced on more complex cognitive tasks (Salthouse, 1991). One element that makes Part B more difficult is the set switching, or cognitive flexibility required by the alternation of numbers and letters (see Gaudino, Geisler, & Squires, 1995 for a more complete discussion of this issue). Prior research suggests that such processes may be subserved by the frontal lobes (e.g., Eslinger & Grattan, 1993; Luria, 1969; Milner, 1964; Stuss & Benson, 1986). Age effects are observed on other tasks thought to rely upon the integrity of the frontal lobes (e.g., concept formation; Albert & Heaton, 1988). In addition, findings from autopsy (Brody, 1955; Kemper, 1995) and neuroimaging studies (Coffey et al., 1992; Pfefferbaum et al., 1994) suggest that the frontal lobes are among those brain regions particularly vulnerable to the effects of normal aging. However, Reitan and Wolfson (1995) found that patients with frontal lesions performed similarly to patients with nonfrontal lesions on TMT Part B. Thus, the neural substrate responsible for the differential age-related performance decrements on TMT Part B compared with Part A are unclear.

Although useful, the data presented here are not strictly normative because they were collected from volunteers participating in a longitudinal study of aging. Specifically, the participants in this study may have performed the TMT up to four times prior to the performances reflected in the tables and figures, and the present sample had, on average, a college education. Moreover, the average age in each group was not exactly at the midpoint of the range, and the sample consisted of 60% males. In light of these considerations, the performances evaluated in this study are not representative of a population-based or clinical sample. However, the effect of prior exposure was limited to Part A, and in only

one age group. Studying volunteers aged 16-69, Stuss, Stethem, and Poirier (1987) reported small and clinically unimportant practice effects on both Parts A and B over a 1-week interval. Nevertheless, the possibility exists that repeated exposure to any cognitive test may reduce the magnitude of age differences and aging effects. We found a small, but significant, education effect on TMT Part B, despite the restricted range of education (97% graduated from high school). This is consistent with prior findings (Richardson & Marottoli, 1996; Stuss et al., 1987). The lack of gender effects is consistent with the few other studies that have considered the potential effect of gender on the TMT (Elias, Robbins, Walter, & Schultz, 1993; Stuss et al., 1987).

Participants with dementia, or suspected of being in the earliest stages of a dementing illness, completed both parts of the TMT more slowly than did cognitively normal participants, and were more likely to make errors in completing either part. Both Parts A and B performed acceptably in ROC analyses. However, Part B showed better specificity to cognitive dysfunction at any given level of sensitivity (see Table 5). Applying the TMT Part B dementia cutoff score (172 s) suggested by Cahn et al., (1995) to the present sample correctly classified participants at a level of accuaracy similar to that in the prior report. It may be noted from Table 5, that 300 s appears to be a useful maximum allowable time for samples resembling the BLSA.

The results from the present study have extended the previous findings of age differences in completion times on the Trail Making Test. The cross-sectional and longitudinal age effects suggest more pronounced age differences and age changes on Part B than Part A. In addition, TMT performance in conjunction with other clinical information may prove useful in detecting early dementia.

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