Introduction

The Trail Making Test (TMT) was developed as part of the Army Individual Test Battery (1944) and was used in 1946 by Armitage to assess the effects of brain injury in soldiers. Later, this test was integrated in the Halstead-Reitan neuropsychological battery (Reitan & Wolfson, 1993). Since then, administration and scoring procedures have varied significantly (e.g., scoring of errors; discontinuation criteria) and alternate forms have been proposed (Atkinson, Ryan, Kryza & Charette, 2011; Salthouse et al., 2000). The TMT is currently one of the most widely used instruments in clinical and experimental neuropsychology (Rabin, Barr, & Burton, 2005; Strauss, Sherman, & Spreen, 2006).

Trail Making Test part A measures attention, visual scanning, and speed of eye-hand coordination and information processing. Part B, additionally, assesses working memory and executive functions, particularly, the ability to switch between sets of stimuli (Lezak, Howieson, & Loring, 2004; Mitrushina, Boone, & D’Elia, 1999; Sanchez-Cubillo et al., 2009). Trail Making Test part B is known to be sensitive to frontal lobe damage (Demakis, 2004; Gouveia, Brucki, Malheiros, & Bueno, 2007; Kaletta et al., 2004; McDonald, Delis, Norman, Tecoma, & Irigui-Madozi, 2005; Stuss, Bisschop, Alexander, Levine, & Katz, 2001). However, no clear association with lesion side has been demonstrated.

The TMT can be a useful indicator of neurological integrity (Larrabee, Millis, & Meyers, 2008; Reitan, 1958; Reitan & Wolfson, 1993; Strauss et al., 2006). It is highly sensitive to a variety of neurological conditions, including head injury (e.g., Heled, Hoofien, Margalit, Natovich, & Agranov, 2012; Lange, Iverson, Zakrzewski, Ethel-King, & Franzen, 2005), Alzheimer’s disease (e.g., Amieva et al., 1998; Ashendorf et al., 2008), dementia with Lewy bodies (Ferman et al., 2006), Huntington’s disease (Lemiere, Decruyenaere, Evers-Kiebooms, Vandenbussche, & Dom, 2004; O’Rourke et al., 2011), and minimal or subclinical hepatic encephalopathy (e.g., Ferenci et al., 2002). The TMT is even sensitive to preclinical manifestations...
of certain neurodegenerative diseases, such as Alzheimer’s disease (Chen et al., 2001) and Huntington’s disease (O’Rourke et al., 2011). In clinical practice, TMT is considered a valuable tool to detect and document changes in cognition. It may also contribute to distinguish between neurological conditions (Ashendorf et al., 2008; Ferman et al., 2006; Heidler-Gary et al., 2007).

Several studies have demonstrated the ecological validity of the test. The TMT is significantly related with performance on instrumental activities of daily living (e.g., safe driving), in community-dwelling older adults and neurological patients (e.g., Bell-McGinty, Podell, Franzen, Baird, & Williams, 2002; Dawson, Anderson, Uc, Dastrup, & Rizzo, 2009; Emerson et al., 2012; Hanks et al., 2008; Mitchell & Miller, 2008). Longitudinal studies have also shown that TMT performance is a good predictor of clinical and functional outcomes, namely conversion to dementia, functional decline, and death in community-dwelling older adults (Chen et al., 2001; Johnson, Lui, & Yaffe, 2007; Vazzaana et al., 2010) as well as in patients with major depression (Potter et al., in press), mild cognitive impairment (e.g., Chapman et al., 2011; Ewers et al., 2012; Gomar et al., 2011), traumatic brain injury (Hanks et al., 2008), or stroke (Wiberg, Kilander, Sundstro, Byberg, & Lind, 2012).

In clinical practice, in addition to the completion times of TMT-A and TMT-B, derived scores are often used for interpretive purposes (Lezak et al., 2004; Mitrushina et al., 1999; Strauss et al., 2006). The most common derived scores are: difference (B − A), ratio (B/A), and proportion (B − A/A). The main reason to use these scores is to reduce the impact of individual variability on part B, by using the subject as his or her own control and also, to remove the components of motor speed and visual scanning speed from part B, by comparing part B to part A. Numerous authors have argued that these derived scores are purer measures of executive functions than the direct raw measures (e.g., Arbuthnott & Frank, 2000; Axelrod, Aharon-Peretz, Tomer, & Fisher, 2000; Corrigan & Hinkeldey, 1987; Drane, Yuspeh, Huthwaite, & Klingler, 2002; Heaton, Nelson, Thompson, Burks, & Franklin, 1985; Hester, Kinsella, Ong, & McGregor, 2005; Horton & Roberts, 2001; Lamberty, Chatel, Bieliauskas, & Linas, 1994; Sanchez-Cubillo et al., 2009; Stuss et al., 2001). However, the difference score is more vulnerable to demographic characteristics than the ratio score (Drane et al., 2002; Hester et al., 2005; Lamberty et al., 1994). Arbuthnott and Frank (2000) provided evidence of a stronger correlation between a non-motor executive control task that involved set-switching and the TMT ratio score, than with direct raw or difference scores. Sum (A + B) and multiplication (A × B/100) have also been explored (Horton & Roberts, 2001; Lange et al., 2005). These two derived scores provide indices of overall cognitive functioning and not just executive functions. Another measure of interest is the number of performance errors (Amieva et al., 1998; Ashendorf et al., 2008; Stuss et al., 2001).

This study aims to explore the influence of sex, age, and education on TMT direct (i.e., time to completion and performance errors for each part) and derived scores (i.e., difference, ratio, proportion, sum, and multiplication scores); and to provide normative data for the Portuguese population that reflect these demographic influences.

Methods

Participants

Subjects included 1,038 community-dwelling Portuguese individuals who were participating in a comprehensive neuropsychological normative project. Participants had between 18 and 93 years of age and between 3 and 22 years of education (i.e., formal schooling completed with success). They were all volunteers and did not receive any monetary compensation. All participants provided their written informed consent in accordance with the Helsinki Declaration.

Recruitment. The participants were recruited in the community via word of mouth. The inclusion criteria were: ≥18 years of age; Portuguese as the first language; have lived in Portugal in the last 5 years; have ≥3 years of education; did ≥50% of formal schooling in Portugal or in a territory with Portuguese administration; and the absence of significant motor, auditory or visual deficits after correction. Each participant’s cognitive normalcy was validated via an informant (i.e., personal physician, relative, friend). Individuals with a history of developmental disorders (e.g., learning disability), neurological disorder (e.g., traumatic brain injury, dementia), or moderate to severe psychopathology (e.g., major depression, psychosis, alcoholism) were excluded.

Comparison between Study Sample and Population Census. The data were collected throughout Portugal (mainland), although the majority of the participants (53%) were recruited in the northern region. The south region, which includes the capital, was underrepresented (only 18% of the study sample). Also, unlike the general population (48% men and 52% women), the number of men participating in the study (31%) was considerably lower than the number of women (69%). The age and the educational background of the normative samples were representative of the Portuguese population. According to the 2011 census (Instituto Nacional de Estatística, 2011), 19% of the Portuguese population are illiterates or did not complete the first cycle of basic
education (i.e., <4 years of education); 25% have four years of education; 29% attained between 6 and 9 years of education; high school was completed by 12%; and ~15% had more than 12 years of education.

**Procedures**

The TMT was part of a comprehensive neuropsychological assessment protocol. Prior to testing, the participant’s clinical history was explored with an interview. The examiners were trained psychologists.

Trail Making Test part A was administered to all participants, whereas part B was only applied to participants with ≥4 years of education.

**Trail Making Test**

**Part A.** The participants were asked to draw lines to connect consecutively 25 encircled numbers. The participants were urged to connect the circles as quickly as possible. Timing was initiated when the participant was asked to start. Participants were allowed to lift the pencil from the page. Whenever an error was made, the examiner pointed it out and explained it. After the explanation, the examiner marked out the wrong part and guided the participant to the last circle completed correctly.

The test condition was not administered if the participant was unable to perform the practice condition (i.e., made more than two errors). The test condition was discontinued after 200 s or after four errors, unless the patient was within three circles of the end. The instructions in Portuguese are available as Supplementary material online.

**Part B.** The participants were asked to draw lines to connect consecutively encircled numbers and letters by alternating between the two sequences (e.g., 1-A-2-B, etc.) progressively up to number 13. The participants were urged to connect the circles as quickly as possible.

Timing was initiated when the participant was asked to start. Participants were allowed to lift the pencil from the page. Whenever an error was made, the examiner pointed it out and explained it. After the explanation, the examiner marked out the wrong part and guided the participant to the last circle completed correctly.

The test condition was not administered if the participant was unable to perform the practice condition (i.e., made more than two errors). The test condition was discontinued after 400 s or after four errors, unless the participant was within three circles of the end. The forms and the instructions in Portuguese are available as Supplementary material online.

**Scoring.** The TMT provided four direct scores and five derived scores. The direct measures of performance were: time (s) to complete part A and part B and performance errors during part A and part B. Based on the direct time scores, five derived scores were calculated: difference score \((B - A)\), ratio score \((B/A)\), proportion score \((B - A/A)\), sum score \((A + B)\), and multiplication score \((A \times B/100)\). Lower raw scores and higher adjusted scores correspond to better performance.

**Statistical Analyses.** Categorical variables were summarized with frequencies and percentages, whereas continuous data were described using means and standard deviations (SD). Scatter plots were used to visualize the associations between demographic variables, and between these variables and test results. Pearson’s correlations \((r)\) and explained variance \((r^2)\) were used to explore the association of demographic characteristics (i.e., age and education) with test performances. The Mann–Whitney test was applied to test the associations between sex and test results. Multiple logistic regression analysis was used to model the odds of discontinuation of part B.

Both direct (time) and derived scores were log transformed due to the skewedness of the distributions. Multiple linear regression analyses were conducted with test scores in the logarithmic scale as dependent variables and demographic variables as covariates. We considered the possibility of a quadratic effect for age and education. The assumptions of homoscedasticity and normal distribution of the residuals were verified. The adjustment of test scores for demographic characteristics was based on regression coefficients. The standardized regression residuals (standardized residuals = residuals divided by the SD) were used to identify the associated percentiles. The residuals represent the difference between the score of an individual and the mean score of individuals with the same age and education obtained by the linear regression. Higher adjusted scores correspond to better performance.
Results

Normative Sample

Trail Making Test part A was administered and completed by 1,038 study participants. Part B was applied to all participants with ≥4 years of education \((n = 986\) participants), but only 922 participants were able to complete the test. Among those that failed to complete part B, 84% had 4 years of education. At this level of education, the frequency of discontinuation was 22%. This frequency decreased to 3% and 2%, respectively for individuals with 5–9 years of education and 10–12 years of education. All participants with ≥12 years of education completed part B. Multiple logistic regression analysis, with sex, age, education, and time to complete part A as independent variables, revealed that the odds of completion increased with education \((\text{adjusted OR} = 1.4, \text{CI} 95\% = [1.2, 1.7]; p < .001)\) and decreased with slower performance at part A \((\text{adjusted OR} = 0.98, \text{CI} 95\% = [0.98, 0.99]; p < .001)\). Sex and age were not significantly associated with the application of the discontinuation rules.

In a posteriori data inspection, TMT A results from 13 participants and TMT B results from 8 participants were excluded from the normative sample, because they were considered outliers (i.e., respectively ≥ 230 s and ≥ 430 s). Trail Making Test part A sample was composed by 1,025 participants \((708\) women and 317 men; mean age = 54.3 years, SD = 17.9, range: 18–93; and mean education = 9.5 years, SD = 4.8, range: 3–22). Trail Making Test part B sample consisted of 914 participants \((622\) women and 292 men; mean age = 52.2 years, SD = 17.5, range: 18–93; and mean education = 10.2 years, SD = 4.7, range: 4–22).

Significant negative correlations were observed between participants’ age and education on both part A \((r = –2.419)\) and part B \((r = –2.343)\) samples. Age and education were not statistically different between men and women \((p > .05)\).

Raw Scores

The mean time to complete part A was 58 s \((SD = 37)\) and to complete part B was 119 \((SD = 73)\). However, both direct time scores presented a skewed distribution \((\text{TMT A} = 1.8 \text{ and TMT B} = 1.6)\). Table 1 presents the means and SDs of direct time scores and derived scores for each sex, age group, and education group. All participants, except two, took longer to complete part B than part A.

The majority of the participants did not make any performance errors at part A (84%) or part B (63%). More than one error at part A or two errors at part B were made by less than 5% of the normative sample. Given the low frequency of errors, no further analysis was done.

| Table 1. TMT direct and derived scores per sex, age, and education groups |
|---|---|---|---|---|---|---|---|
| | Direct scores | | Derived scores | | |
| | Part A \((n = 1025)\) | Part B \((n = 914)\) | | B – A | B/A \((\text{M}\ SD)\) | B – A/A \((\text{M}\ SD)\) | A + B \((\text{M}\ SD)\) | A x B/100 \((\text{M}\ SD)\) |
| n | % | M (SD) | MIN—MAX | n | % | M (SD) | MIN—MAX | | | |
| Sex | | | | | | | | | | | |
| Women | 708 | 69 | 61 (37) | 17–225 | 622 | 68 | 122 (73) | 33–401 | 69 (54) | 2.4 (0.9) | 1.4 (0.8) | 176 (98) | 82 (106) |
| Men | 317 | 31 | 52 (37) | 13–224 | 292 | 32 | 113 (71) | 29–418 | 66 (51) | 2.5 (1.0) | 1.5 (1.0) | 160 (96) | 69 (95) |
| Age | | | | | | | | | | | |
| 18–29 | 136 | 13 | 31 (11) | 13–83 | 136 | 15 | 68 (26) | 29–198 | 37 (22) | 2.3 (0.8) | 1.3 (0.8) | 99 (32) | 22 (15) |
| 30–39 | 123 | 12 | 36 (13) | 14–80 | 120 | 13 | 84 (37) | 32–278 | 48 (31) | 2.5 (0.9) | 1.5 (0.9) | 119 (45) | 32 (24) |
| 40–49 | 109 | 11 | 47 (20) | 19–130 | 107 | 12 | 112 (57) | 34–300 | 66 (44) | 2.5 (0.9) | 1.5 (0.9) | 158 (72) | 59 (60) |
| 50–59 | 212 | 21 | 51 (27) | 15–206 | 200 | 22 | 113 (61) | 47–360 | 65 (49) | 2.4 (0.9) | 1.4 (0.9) | 162 (77) | 64 (67) |
| 60–69 | 217 | 21 | 60 (29) | 20–182 | 191 | 21 | 131 (67) | 50–401 | 77 (53) | 2.5 (0.9) | 1.5 (0.9) | 186 (85) | 83 (78) |
| 70–79 | 144 | 14 | 90 (43) | 24–225 | 105 | 12 | 172 (89) | 49–401 | 94 (68) | 2.3 (0.8) | 1.3 (0.8) | 250 (119) | 158 (147) |
| ≥80 | 84 | 8 | 109 (49) | 44–224 | 55 | 6 | 219 (89) | 76–418 | 124 (66) | 2.4 (0.7) | 1.4 (0.7) | 314 (125) | 236 (193) |
| Education | | | | | | | | | | | |
| 3 | 51 | 5 | 120 (43) | 42–218 | | | | | | | | |
| 4 | 238 | 23 | 84 (43) | 25–225 | 187 | 21 | 191 (83) | 48–401 | 118 (64) | 2.8 (1.0) | 1.8 (1.0) | 265 (110) | 162 (139) |
| 5–9 | 272 | 27 | 52 (27) | 15–169 | 266 | 29 | 121 (63) | 38–398 | 69 (46) | 2.5 (0.9) | 1.5 (0.9) | 174 (87) | 78 (98) |
| 10–12 | 189 | 18 | 46 (23) | 13–168 | 186 | 20 | 100 (57) | 29–418 | 54 (41) | 2.3 (0.8) | 1.3 (0.8) | 147 (76) | 57 (75) |
| >12 | 275 | 27 | 38 (17) | 14–183 | 275 | 30 | 81 (40) | 32–385 | 43 (31) | 2.2 (0.8) | 1.2 (0.8) | 119 (54) | 36 (44) |

Test scores are presented as means (M), standard deviations (SD), minimum (MIN), and maximum (MAX).
Women on part A ($p = .015$), part B ($p = .017$), sum ($p = .001$), and multiplication ($p < .001$). However, women showed better ratio ($p = .006$) and proportion ($p = .006$) scores than men. The difference score was not statistically associated with sex ($p = .784$). The effects of age and education on test scores were also investigated and significant linear associations were found (Table 2). Both age and education were significantly correlated with direct scores. Education was associated with all derived scores, whereas age was significantly related only with three derived scores (i.e., difference score, sum, and multiplication score). Scatter plots revealed that the relation between demographic variables and TMT scores had quadratic shapes.

After TMT direct scores and derived scores were converted to a logarithmic scale, multiple regression analyses were conducted with variables sex, age, age squared, education, and education squared as covariates. The regression model partly explained ($r^2$) the variance of part A (57%), part B (50%), B – A (32%), B/A (7%), B – A/A (7%), A + B (54%), and A × B/100 (55%). Each independent variable of the multiple regression models remained statistically associated ($p < .05$) with both direct time measures. The univariate (Table 2) and multivariate regression analyses revealed a similar pattern of significant associations ($p < .05$) between derived scores and demographic variables. Education was the only demographic variable to be significantly related ($p < .05$) with all TMT direct and derived measures, after adjusting for sex and age.

**Demographic Effects**

Regression-based algorithms were developed to adjust direct and derived test scores for sex, age, and education (Table 3). In other words, the algorithms convert “raw” scores of an individual into standardized Z scores. The percentiles and the scaled...
scores associated with the adjusted scores are shown in Table 4. When time to complete part B is equal or less than part A, the adjusted scores for derived scores difference and proportion could not be calculated.

A user-friendly program is available online (http://neuropsi.up.pt/) to adjust direct and derived scores (Fig. 1). The clinician only needs to introduce the subject’s sex, age, education, and time to complete part A and part B. For instance, if a man with 43 years of age and 9 years of education completes TMT part A in 60 s and part B in 160 s, the adjusted scores are $-1.7$ for part A

<table>
<thead>
<tr>
<th>Percentile ranks</th>
<th>Scaled scores</th>
<th>Adjusted scores</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Part A</td>
<td>Part B</td>
</tr>
<tr>
<td>1</td>
<td>3</td>
<td>$-2.5$</td>
</tr>
<tr>
<td>2</td>
<td>4</td>
<td>$-2.1$</td>
</tr>
<tr>
<td>3–5</td>
<td>5</td>
<td>$-1.9$, $-1.6$</td>
</tr>
<tr>
<td>6–10</td>
<td>6</td>
<td>$-1.5$, $-1.3$</td>
</tr>
<tr>
<td>11–18</td>
<td>7</td>
<td>$-1.2$, $-0.9$</td>
</tr>
<tr>
<td>19–28</td>
<td>8</td>
<td>$-0.9$, $-0.6$</td>
</tr>
<tr>
<td>29–40</td>
<td>9</td>
<td>$-0.6$, $-0.3$</td>
</tr>
<tr>
<td>41–59</td>
<td>10</td>
<td>$-0.3$, $-0.3$</td>
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<tr>
<td>60–71</td>
<td>11</td>
<td>$0.3$, $0.6$</td>
</tr>
<tr>
<td>72–81</td>
<td>12</td>
<td>$0.6$, $0.9$</td>
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<tr>
<td>82–89</td>
<td>13</td>
<td>$1.0$, $1.2$</td>
</tr>
<tr>
<td>90–94</td>
<td>14</td>
<td>$1.3$, $1.5$</td>
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<tr>
<td>95–97</td>
<td>15</td>
<td>$1.6$, $1.8$</td>
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<td>98</td>
<td>16</td>
<td>$2.0$</td>
</tr>
<tr>
<td>99</td>
<td>17</td>
<td>$2.2$</td>
</tr>
</tbody>
</table>

Fig. 1. Screenshot of the online tool to compute the adjusted TMT scores (http://neuropsi.up.pt).
Discussion

Trail Making Test normative data are presented as algorithms to adjust test scores for sex, age, and education, with subsequent correspondence between adjusted scores and percentile distributions. The adjusted scores can be interpreted as $z$ scores, because they have normal distribution with mean $\mu = 0$ and $SD = 1$. The percentile ranks can be converted into scaled scores (i.e., mean $= 10$ and $SD = 3$). These standardization procedures have significant advantages for both clinical and research practices. The adjustment to the individual’s demographic characteristics and the use of common metrics allow the comparisons between tests and between individuals.

In agreement with most normative studies, TMT performance declined with age and improved with education (e.g., Ashendorf et al., 2008; Cangoz, Karakoc, & Selekler, 2009; Giovagnoli et al., 1996; Goul & Brown, 1970; Kennedy, 1981; Lucas et al., 2005; Pena-Casanova et al., 2009; Salthouse et al., 2000; Seo et al., 2006; Steinberg, Bieliauskas, Smith, & Ivnik, 2005; Tombaugh, 2004; Zalonis et al., 2008). The influence of these demographic characteristics on test performance appears to be more pronounced in this study than in previous reports. The strong effects of age and educational level probably reflect the heterogeneity of the normative sample, which is representative of the Portuguese population. Noteworthy, the number of years of education was significantly related to all direct and derived TMT scores, even after adjusting for sex and age. Measures of speed of performance (i.e., completion time, difference, sum, and multiplication) were highly influenced by age, but similar to previous studies (Hester et al., 2005; Lamberty et al., 1994) neither ratio nor proportion scores were related with age. Significant associations were found between sex and TMT performance. In general, women were slower than men, even after adjusting for age and education. However, women showed better ratio and proportion scores than men. Nonetheless, in agreement with other reports (Cangoz et al., 2009; Giovagnoli et al., 1996; Hester et al., 2005; Ivnik, Malec, Smith, & Tangalos, 1996; Seo et al., 2006), the effects of gender on TMT performance were less pronounced than those of age and education.

The influence of demographic characteristics on direct and derived scores varied considerably. As expected (Corrigan & Hinkeldey, 1987; Lamberty et al., 1994; Strauss et al., 2006), these effects were larger for raw completion times and for derived scores that resulted from difference, sum and multiplication, than for ratio or proportion scores. This variability raises the issue of interpreting TMT performance, particularly the derived scores, with reference to the subject’s demographic characteristics. As demonstrated by the example presented in the results’ section, the same test scores may produce diverging results among demographically adjusted derived scores. The ratio and the proportion scores are believed to be TMT’s most sensitive indices for detecting impairments in executive functions, because they are less vulnerable to demographic characteristics (Corrigan & Hinkeldey, 1987; Lamberty et al., 1994).

Educational restrictions were applied to the collection of data because TMT requires specific knowledge (e.g., numerical and alphabetical sequences) that is traditionally acquired in formal education. Even with these restrictions, part B was discontinued in $\sim 6\%$ of participants. The large majority ($84\%$) of those that failed to complete part B only had 4 years of education. At this level of education, the frequency of discontinuation was considerable ($22\%$). These data suggest that poor performance on TMT B may not be a reliable indicator of cognitive dysfunction in individuals with only 4 years of education.

In this normative study, education was operationalized as the number of years of formal regular schooling completed with success. Equivalences from the “New Opportunities program” initiative (a governmental program designed to enhance school certification and qualification levels of the Portuguese adult population) were not credited. This approach is vulnerable to the numerous changes in the educational system that have occurred throughout the last decades in Portugal. For most of the twentieth century, letters “K”, “W”, and “Y” were not part of the alphabet taught in the Portuguese primary schools. Even though the current teaching includes this set of letters and some foreign words written with “K” have since entered the lexicon, TMT part B stimulus did not include letter “K”. Considering these continuing changes, future studies ought to assess the reliability of the forms and normative algorithms and update the norms if necessary.

The study sample was representative of the Portuguese population regarding age and education, but not for sex or region of residence. It is unlikely that the overrepresentation of women in the study sample has produced a significant bias on the study results, due to (a) the large sample size, (b) the absence of significant associations between sex and other demographic variables, and (c) the adjustment of all TMT scores for sex. On the basis of the relatively small size of the country and its considerable migration, we do not expect geography to have a significant impact on the Portuguese norms.
Trail Making Test data were collected and norms were developed as part of a larger project that aims to standardize a series of widely used neuropsychological instruments. The norms for all measures are being developed within the same (or substantially overlapping) study sample. This co-norming approach is believed to facilitate the comparison between test scores, which enhances the precision of cognitive pattern analysis in clinical settings and allows for a greater diagnostic accuracy (Lucas et al., 2005). The collection of data from multiple tests is also beneficial because it provides a closer parallel to the clinical setting.

Supplementary Material

Supplementary material is available at Archives of Clinical Neuropsychology online.

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Conflict of Interest

None declared.

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