NeuroRehabilitation 49 (2021) 215–220
DOI:10.3233/NRE-218021
IOS Press

The adapted symbol digit modalities test: Examining the impact of response modality

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Abstract.
BACKGROUND: Information processing speed is often impaired in neurological disorders, as well as with healthy aging. Thus, being able to accurately assess information processing speed is of high importance. One of the most commonly used tests to examine information processing speed is the Symbol Digit Modalities Test (SDMT), which has been shown to have good psychometric properties.
OBJECTIVES: The current study aims to examine differences between two response modalities, written and oral, on the performance of an adapted version of the Symbol Digit Modalities Test.
METHODS: Ninety-nine individuals completed two alternate forms of the adapted version of the SDMT (aSDMT). Participants were instructed to complete the five lines of the task as quickly and accurately as possible. On one form participants were instructed to provide their response in writing and on the other one, orally. Form and response modality (oral vs. written) were counterbalanced to control for practice effects.
RESULTS: On average, there was a significant difference between response modalities, such that participants needed more time to respond when the response modality was written. For both response modalities, time to complete each line of stimuli decreased as the task progressed. While changes in response time on the first four lines of stimuli on the oral version were not found, there was a substantial improvement in response time on the fifth line. In contrast, on the written version a gradual learning effect was observed, in which response time was the slowest on the first two lines, an intermediate response time was noted on line 3, and the fastest response time was achieved on lines four and five.
CONCLUSION: The current study demonstrates that response modality, oral versus written, can significantly impact performance efficiency (the length of time it takes to complete a task), but not accuracy (total correct responses), on a new adaptation of the SDMT, the aSDMT.

Keywords: Adapted symbol digit modalities test, oral versus written version

1. Introduction

Information processing speed (IPS) is a common deficit in several neurological disorders, such as multiple sclerosis (Chiaravalloti & DeLuca, 2008; Costa, Genova, DeLuca, & Chiaravalloti, 2017), traumatic brain injury (Kinnunen et al., 2011), spinal cord injury (Molina et al., 2018), schizophrenia (Schaefer, Giangrande, Weinberger, & Dickinson, 2013), Alzheimer's disease and mild cognitive impairment (Phillips, Rogers, Haworth, Bayer, & Tales, 2013). Normal aging has similarly been associated with significant declines in IPS (Salthouse, 2018).

Individuals with IPS deficits have higher levels of unemployment (Rao et al., 1991; Strober, Chiaravalloti, Moore, & Deluca, 2014; Strober et al., 2012), greater driving difficulties (Schultheis et al., 2010;

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Schultheis, Weisser, Manning, Blasco, & Ang, 2009), and impairment in daily life activities (Barker-Collo, 2006; Kalmar, Gaudino, Moore, Halper, & DeLuca, 2008). Chiaravalloti and colleagues (Chiaravalloti & DeLuca, 2015) recently demonstrated that individuals with IPS deficits benefit less from learning and memory rehabilitation then those with intact IPS. In fact, Salthouse (Salthouse, Fristoe, & Rhee, 1996) and others (Costa et al., 2017) have shown that IPS is the basis of several cognitive impairments in aging and other neurological pathologies. It is thus unquestionable that in order to fully understand the impact of neurological disorders and its associated declines, one needs to assess IPS.

Information processing speed is frequently assessed with the Symbol Digit Modalities Test (SDMT; Smith, 1991), a test shown to be sensitive to disease progression and predictive of various functional outcomes in several neurological pathologies (e.g. Akbar, Honarmand, Kou, & Feinstein, 2011; Benedict et al., 2017; Charvet, Beekman, Amadiume, Belman, & Krupp, 2014; Hinton-Bayre, Geffen, & McFarland, 1997; Pavlou et al., 2017). The SDMT has many advantages including ease of administration, good reliability, predictive validity, sensitivity and specificity (Benedict et al., 2017). More specifically, the SDMT was found to be the best discriminator of dementia and depression of eight neuropsychological tests administered (Pfeffer et al., 1981). Fleisher and colleagues (Fleisher et al., 2007) similarly found that the SDMT was the best predictor of progression from mild cognitive impairment to Alzheimer disease. In multiple sclerosis (MS), the SDMT was found to be the best predictor of future cognitive decline (Amato et al., 2010; Strober, Rao, Lee, Fischer, & Rudick, 2014) and functional impairment, namely unemployment. It is thus not surprising that the SDMT is the single test common to all cognitive batteries recommended to assess cognition in MS, such as the Minimal Assessment of Cognitive Function in Multiple Sclerosis (Benedict et al., 2006), the Brief Repeatable Battery (Rao, 1991), MS-Cog (Erlanger et al., 2014), and Brief International Cognitive Assessment for Multiple Sclerosis (Langdon et al., 2012). Moreover, the SDMT was deemed the one core Common Data Element for use in MS by the National Institute of Neurological Disorders and Stroke in 2011 (Benedict, Krupp, Francis, & Al., 2012).

Although widely used, the SDMT has several limitations that are often overlooked: there are disproportionate learning opportunities for each number/symbol, there is potential bias for some symbols as they can be verbalized, and not all participants will progress equally as far on the task as the task is terminated after 90 seconds have elapsed leading to inequality between participants in regard to the degree of challenge of the task (for a complete discussion see (Costa et al., n.d.).

In the SDMT, and similarly in its modified versions (for a complete review see Silva, Spedo, Barreira, & Leoni, 2018), participants are presented with a set of symbols and corresponding numbers on the top of the page. Underneath, symbols are presented with an empty box below and participants are asked to call out (oral version) or write (written version) the number that is paired with each of the symbols in the key. In populations with neurological disorders, oral responses are frequently recommended/used to overcome upper limb motor limitations. The oral version of the SDMT is typically utilized in both research and clinical care in MS. However, studies examining the impact of response modality on performance of the SDMT are scarce. A few studies have shown that individuals perform better on the SDMT when response modality is oral in comparison with written (Fellows & Schmitter-Edgecombe, 2019; Smith, 1991). However, there are two important limitations across all these studies, the written SDMT was always performed first, thus biasing the results, and no secondary analysis were performed to investigate the reason for differences between the oral and written versions. It is thus not possible to determine the source of performance differences, deficits in cognition, training effects or the impact of response modality.

The current study sought to examine the impact of response modality (written or oral) on performance accuracy and efficiency on an adapted version of the SDMT (aSDMT), designed to address the learning and task difficulty concerns inherent within the standard SDMT (Costa et al., n.d.). Since this is a new adaptation of a previously existing, but widely-utilized test, it is important to carefully understand how modifications to administration might significantly impact performance. It was hypothesized that response modality would not affect performance accuracy, however, it was expected that participants would complete the task faster when response modality was oral (performance efficiency). It was additionally expected that learning patterns throughout the task would be dependent on response modality.

2. Methods

2.1. Participants

Ninety-nine healthy participants from Bar-Ilan University, Israel, were enrolled in the study. Participants were on average 23.28, ($SD = 2.84$) years old and had 12.77, ($SD = 1.31$) years of education. The sample was 58.6% female and 41.4% male. All participants signed an informed consent form approved by the Institution Review Board before enrolling in the study.

For this study we included participants between the age of 18–28. Exclusion criteria included, less than 12 years of education, diagnosed visual perceptual deficits as well as learning or attention deficit disorders.

2.2. Procedures

The aSDMT was developed to overcome the SDMT limitations. Similar to the original SDMT, a key of nine numbers with nine corresponding symbols is presented on the top of the paper. Underneath, symbols are presented with an empty box below and participants are asked to call out (oral version) or write (written version) the number that is paired with each of the symbols in the key. There are 5 lines of stimuli to be completed. Several key features of the aSDMT distinguish it from the SDMT. (1) The participants must complete all 5 lines of stimuli and time to completion is the dependent variable. (2) Each symbol appears at the same frequency within each line and throughout all 5 lines (3) In any given line, the same symbol cannot appear following the symbol it followed in the line above.

Two versions of the aSDMT (aSDMT 1 and aSDMT 2) were developed using a MATLAB code that randomizes the symbol distribution throughout the five lines (Costa et al., n.d.). Participants are instructed to orally state (aSDMT - O) or write (aSDMT - W) which number correctly pairs with each symbol, according to the key presented on the top of the page, starting at the first symbol on first line. All participants are instructed to provide the fastest and most accurate answer possible to all 90 symbols. The aSDMT versions (1 and 2) and response type (oral and written) were counterbalanced to control for order effects (Fig. 1). The measures of interest were: total time to complete the task, total correct responses.

2.3. Statistical analysis

Two repeated measures ANOVAs were conducted to assess performance on the aSDMT. Factors in the first model included response modality (written versus oral) and total time to complete each line (lines 1 to 5). The second model included response modality (written versus oral) and total correct responses. Two *post-hoc* repeated measure ANOVAs were performed to examine performance on each of the five lines for each response modality (written and oral).

3. Results

Repeated measure ANOVA showed a significant main effect of response modality ($F\ (1, 98) = 38.75$, $p < 0.01$, $\eta_p^2 = 0.28$). On average, total time to complete the aSDMT was significantly faster on the aSDMT-O in comparison to the aSDMT-W. Additionally, there was a significant main effect of line ($F\ (3, 290) = 19.67$, $p < 0.01$, $\eta_p^2 = 0.17$) such that as participants progress through the task, less time is required to complete each line (Fig. 2). The interaction of response modality and line was also significant ($F\,(4, 392) = 2.61$, $p < .04$, $\eta_p^2 = 0.03$). When response modality was oral, participants needed less time to execute line 5 in comparison with all of the previous four lines (line 1 $p < 0.01$, line 2 $p < 0.01$, line 3 $p < 0.01$, and line 4 $p < 0.01$). When response modality was written, participants became more efficient by line 4. On average participants needed less time to complete line 4 in comparison with line 1 ($p = 0.05$) and line 2 ($p < 0.01$). The same results were found for line 5 such that less time was required to complete line 5 in comparison with line 1 ($p < 0.04$) and line 2 ($p < 0.01$). Thus, findings suggest that on the oral version there is not a significant improvement in response time in the first four lines, but a sharp improvement in the final, fifth line. On the written version however, we observed a gradual learning effect, where response time is the slowest on first two lines, an intermediate response time on the third line, and the fastest response time on lines four and five lines (see Fig. 2).

The number of total correct responses was not significantly different between SDMT-O and SDMT-W ($F\ (1, 98) = 3.45$, ns), nor was there a significant difference in total correct responses as one progressed from line 1 to line 5 ($F\ (4, 392) = 0.58$, ns). Additionally, the interaction of response modality x line ($F\ (4, 392) = 0.47$, ns) was not significant. On aver-

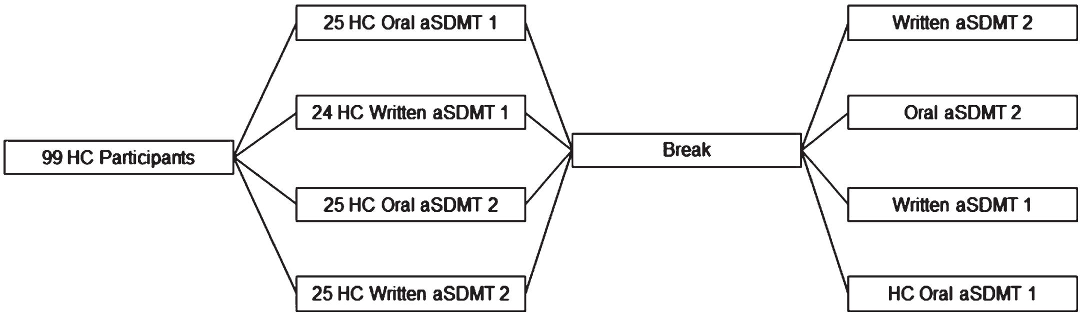

Fig. 1. Protocol: participants were divided into four groups to counterbalance the effects of presentation order (aSDMT 1 and aSDMT2) and modality order (oral and written).

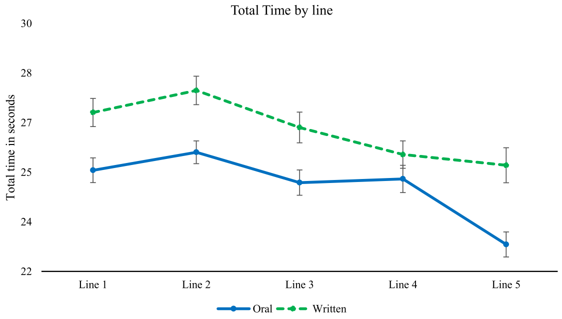

Fig. 2. Total time to successfully complete the five lines on the aSDMT by modality (oral and written).

age, participants obtained 89.23 (*SD* = 1.41) correct responses on the aSDMT-O and 89.55 (*SD* = 1.16) on the aSDMT-W.

4. Discussion

It is now well accepted that the SDMT and modified versions of the SDMT are very sensitive to brain pathology in several neurological diseases, such as MS. However, it is not yet understood how different components of the test affect performance accuracy and efficiency. The current study showed that in healthy participants, response modality, oral versus written, can significantly impact performance efficiency (the length of time it takes to complete the task), but not accuracy (total correct responses), on a new adapted SDMT, developed to overcome limitations found on the standard SDMT.

On average, participants showed high levels of performance accuracy, independent of response modality. Comparable performance accuracy results on the aSDMT were similarly reported by Costa et al (Costa et al., n.d.) in a pilot study examining performance on the aSDMT by participants with MS as well as healthy controls. Past research using the standard SDMT often only report efficiency results (total correct responses within 90 seconds) and thus little is known about untimed accuracy. Accuracy results on different modified versions of the SDMT (mSDMT) have been somewhat contradictory in the literature, with some studies reporting high levels of accuracy for healthy controls and individuals with MS (Forn et al., 2013; Forn et al., 2009; Genova, Hillary, Wylie, Rypma, & Deluca, 2009) and at least one reporting that individuals with MS show a higher number of errors in comparison with a healthy control group (Akbar et al., 2011).

Results of the current study indicated that performance efficiency (how long it takes to complete the task) was related to response modality, such that when a response was provided orally, participants were able to complete the task faster. The effects of response modality appear on line 1 and continue throughout the task. As participants progress throughout the task, time to complete each line decreases for each response modality, but in different patterns. When response modality is written, time to complete each line starts to significantly decline between line 2 and 3, however a similar decline is only found between line 4 and 5 when response modality is oral, and this can be related with different components of the test. There are several potential explanations for this finding.

First, this pattern of results could be associated with learning. That is, studies have shown that information that is written tend to be learned faster (Tynjälä, Mason, & Lonka, 2001). For example, the dual coding theory by Pavio (Paivio & Csapo, 1973) suggest that encoding with more than one modality (in this case visual and motor - write the number) improves learning and memory. Past research examining the impact of learning and memory on the SDMT have produced contradictory results. Patel and colleagues (Patel, Walker, & Feinstein, 2017) examined the impact of learning and memory on performance of two different versions of a computerized SDMT (c-SDMT). Similar to the standard SDMT, on the c-SDMT participants saw a key on the top of the screen and symbols on the bottom. In one version (fixed c-SDMT) the key was the same throughout the task, and on the other version (variable c-SDMT) the key changed eight times. Results indicated that throughout the task there was a trend for improvement on the fixed c-SDMT, but not on the variable c-SDMT. Additionally, immediate visual memory recall was found to be associated with performance on the fixed c-SDMT but not with the variable c-SDMT. Authors concluded that incidental visual memory impacts performance on the fixed c-SDMT. One of the limitations of Patel and colleagues study however is that the variable and fixed c-SDMT were performed by two different groups, thus results could have potentially be due to differences between the two groups. Denny and colleagues noted contradictory results on a different c-SDMT. In an effort to examine the impact of incidental learning on SDMT performance, Denny and colleagues examined total correct responses over the course of 90 second intervals. Over the course of the c-SDMT, the rate of item completion did not increase for individuals with MS and HC, leading to the conclusion that a greater ability to learn the symbol-digit association in the SDMT is not a factor in the difference in performance between healthy individuals and individuals with MS.

A second potential explanation for this finding is the fact that written responses allow participants to review previous responses, avoiding spending time referencing the key.

A third consideration in interpreting these results is the fact that written responses provide a visual anchor for the participant, lessening the role of visuospatial search strategies. That is, the participant can use the last drawn symbol as an anchor of their progress and next step. When the response modality is oral, the task becomes more challenging as participant progress since participants need to keep the location of their current symbol in working memory.

Tests with oral responses are often preferred when working with populations with neurological disorders due to the high frequency of impaired upper-limb dysfunction (i.e. MS). It is often assumed by clinicians and researchers alike that response modality does not significantly change the task. However, the current study shows is that response modality can significantly impact performance efficiency of the aSDMT. This is important to consider when utilizing the aSDMT and the SDMT, for both, clinical and research purposes.

Although results of the current study increase our understanding of performance efficiency on the aSDMT, the study has some important limitations. First, we do not have a complete neuropsychological assessment for the participants, which precludes the examination of the relationship between learning and memory abilities and performance on the aSDMT. Additionally, we did not administer the standard SDMT in this study. We are therefore unable to compare with the SDMT and aSDMT in this sample. Nevertheless, a recent study by Costa et al (Costa et al., n.d.) noted the aSDMT to significantly correlate with the standard SDMT.

5. Conclusion

Understanding the etiology of impaired performance on the SDMT/aSDMT/mSDMT is essential. It is only through a complete understanding of the etiology of the observed deficits that researchers and clinicians will be able to develop efficient rehabilitation programs to treat information processing speed impairments, a common and debilitating impairment in MS and other neurological disorders. During the ongoing COVID 19 pandemic, researchers and clinicians were forced to adjust assessments to the new reality; for example neuropsychological assessments were most commonly conducted online. The current study highlights the importance of carefully studying test modifications (even with a simple change such as response modality) and its impact on performance.

Conflict of interest

None to report.

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