COMPUTER TECHNOLOGY

An automated version of the digit symbol substitution test (DSST)

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An automated version of the Digit Symbol Substitution Test is described that employs a relatively inexpensive, commercially available microcomputer to present and score the task. Advantages of the automated DSST include: (1) objective scoring of both speed and accuracy of test performance, (2) printed copies of test scores, (3) convenient administration under standardized test conditions, and (4) the capacity for repeated assessment of an individual's performance over time. Task performance data for individual subjects following doses of pentobarbital are presented; these data illustrate both the stability of task performance under constant conditions and the within-subjects sensitivity of task performance to experimental manipulations.

The Digit Symbol Substitution Test (DSST), a component of the Wechsler Adult Intelligence Scale (Wechsler, 1958), is frequently used to measure associative ability. The DSST is also a popular instrument for the assessment of performance following administration of pharmacological agents. Indeed, it appears to be one of the more sensitive tasks used for this purpose (Hindmarch, 1980; McNair, 1973; Wittenborn, 1979).

The DSST typically is administered as a paper-and-pencil task. A subject is given a digit-symbol code in which each of nine digits is paired with a different symbol. On the same page (located below the code), a series of digits, selected from those in the code, is presented in an irregular order. The subject is instructed to draw the symbol that is appropriate for each digit in the space below each digit and to draw as many correct symbols as possible within a 90-sec test period.

The present paper describes an automated version of the DSST that can be implemented easily on a commercially available personal microcomputer. This computerized version of the task offers advantages over the traditional pencil-and-paper version in terms of convenience, objective scoring, repeated measurement, and experimental control.

METHOD

With the automated DSST, the digit-symbol code is constantly displayed at the top of the video screen and the test digits are presented, one at a time, in the center of the screen. The subject's task is to enter, on the microcomputer keyboard, the geometric pattern of keypresses, shown in the digit-symbol code, which corresponds to the test digit. The microcomputer controls each 90-sec test session, scores the test, and stores the results; there is no need for a test administrator to be present during the test session.

To implement the DSST program that controls the procedures described below, we use a TRS-80[®] Model I or Model III microcomputer (Radio Shack) with Level II BASIC and numeric key pad, a cassette tape recorder to load and save the program, and a peripheral interface package manufactured by the LVB Corporation (Lehigh Valley, Pennsylvania). The interface package includes a 1080-54 programmable timer card, 1080-01 bus extension, and a 1081-72 daisy chain cable. A Quick Printer II[®] (Radio Shack) is a useful system addition for providing printed records of test data.

Figure 1 (Panel A) illustrates the video display during the automated DSST. Each time a subject initiates the task, one of nine possible digit-symbol codes is randomly selected. For each code, a pattern of asterisks and hyphens is assigned to each of the numbers from one to nine, with the restriction that no two numbers are associated with the same geometric pattern. The nine numbers and their assigned patterns are displayed at the top of the video screen. In addition, one of the numbers is randomly selected to appear in the center of the screen as a test digit.

The subject's task is to use the numeric key pad at the right of the keyboard (displayed in Panel B of Figure 1) to reproduce the geometric pattern associated with each number that appears in the center of the screen. The 3 by 3 grid of asterisks and hyphens associated with each digit functions as a map of the 3 by 3 numeric key pad grid; asterisks indicate which key pad

This work was supported by USPHS Research Grants DA-01022 and DA-01943, Research Training Grant DA-07209, Research Scientist Development Award DA-00050, and Biomedical Research Support Grant RR-05556. We thank Larry Chait, Betsy McCaul, and Maxine Stitzer for helpful comments on the manuscript, and David O'Leary for figure preparation. Reprints and printed copies of the program may be obtained from Roland R. Griffiths, Psychiatry, 623 Traylor Building, Johns Hopkins University School of Medicine, Baltimore, Maryland 21205. For a taped copy of the program, please send a blank cassette and specify TRS-80 Model I or III.

locations must be pressed to reproduce the correct geometric configuration. To be correct, the position of the pressed key in each row of the numeric key pad (not the number printed on the key) must correspond to the position of the asterisk in each row of the appropriate pattern. As the subject presses a key in the correct row of the numeric key pad, an asterisk (corresponding to the position of the pressed key) and two hyphens are displayed in a row below the test digit in the center of the screen (see "Test-Digit Display" in Panel B of Figure 1). The correct keys in the three rows of the numeric key pad must be pressed sequentially from top to bottom. A deviation from this sequence produces only a row of hyphens below the test digit but does not terminate the trial. Once three keys have been pressed, the test digit in the center of the screen changes.

Figure 1 also provides an example of the pattern-reproduction procedure. Since the number 6 was displayed in the center of the video screen, the correct sequence of keypresses on the numeric key pad (shown from left to right in Panel B) is as follows: left key in Row 1, left key in Row 2, and center key in Row 3.

The task is completed when 90 sec have elapsed, provided the subject has finished keying in the pattern associated with the last digit to appear in the center of the screen.

When a subject has completed a 90-sec test session, the number of correct patterns reproduced and the number of patterns attempted during the session are displayed briefly on the video screen. In our application, the task cannot be administered again until the data have been recorded or printed out by the experimenter. This procedure ensures that the experimenter obtains a score each time the task is administered; that is, it is not possible for a subject to repeat the task immediately and thereby erase the data from a preceding test session.

Figure 1. Schematic representation of the automated DSST. Panel A: Video screen with digit-symbol code and test digit displayed. Panel B: Sequence of changes in the test-digit display on the video screen as each key on the numeric key pad is pressed. The response sequence is from left to right. Darkened squares represent keypresses; squares with hatchmarks represent previously pressed keys. Following each keypress, the row of asterisk and hyphens associated with the pressed key appears below the test digit; following the third keypress, a new digit appears in the center of the screen. To be counted as correct, the positions of the pressed keys (Panel B) must correspond to the positions of the asterisks in the geometric pattern below the test digit in the digit-symbol code (Panel A).

Figure 2. Flow diagram of the automated DSST procedure (see text for explanation).

Figure 2 presents a flow diagram of the DSST procedure. The subject presses "S" to initiate the task. If the experimenter has already recorded the data from the previous test, instructions are presented to the subject, who then has the option of a practice trial (by pressing "P") or the test series (by pressing "S"). The correct reproduction of a pattern during the practice trial automatically moves the program to the directions for the test series; an error results in a repetition of the practice trial. Ninety seconds after the task is initiated, the test session is complete and the subject's score appears on the screen for 5 sec. The screen then displays the initial instruction again. If the subject attempts to initiate the task before the data from the previous session have been recorded, the message "COLLECT DATA" appears on the screen for 1 sec. To recall the data from storage, the experimenter presses the "D" key; the function of the "D" key is not explained to the subject. When the "F" key is pressed, the initial instruction is again displayed on the screen. If the data have been collected already, the message "DATA COLLECTED ALREADY" appears on the screen for 1 sec.

EVALUATION

Hindmarch (1980) has pointed out that the assessment of experimental manipulations on DSST performance should be preceded by sufficient training to produce a relatively stable baseline performance. Figure 3 presents the number of correct patterns reproduced by three previously untrained volunteers who were exposed to the automated DSST for 25 consecutive test sessions.

Figure 3. Number of correct geometric patterns reproduced by three subjects during their first 25 successive exposures to the automated DSST. Y-axis: Number of correctly reproduced patterns in 90 sec. X-axis: Successive DSST test sessions. Each subject took approximately 1 h to complete 25 test sessions.

The 25 sessions were completed within 1 h, and relatively little further improvement in performance occurred following 5-10 sessions of training. With the automated version of the DSST, therefore, a suitably stable baseline performance can be obtained within 30 min of massed practice.

To examine the sensitivity of the automated DSST to drug administration, we assessed the effects of placebo and three doses of pentobarbital on the DSST performance of three volunteer subjects who had histories of sedative abuse but were not physically dependent on drugs. A subject received each dose at least five times and performed the automated DSST 2 h after receiving the drug. The group mean number of correct patterns reproduced following doses of pentobarbital (200, 400, and 600 mg) is displayed in Figure 4 (top panel). A repeated-measures analysis of variance revealed a significant dose-related decrement in DSST performance ($p < .001$).

With paper-and-pencil versions of the DSST, the number of correctly reproduced symbols typically is used to characterize DSST performance. Another measure of task performance, often ignored or difficult to obtain with the traditional version of the test, is the accuracy of symbol reproduction (the ratio of correct to attempted reproductions). With the present automated DSST, subjects are not given the opportunity to modify responses (e.g., to correct errors) once they have been made; both correct and incorrect responses are recorded, and performance accuracy is readily calculated. Figure 4 (bottom panel) shows that the performance accuracy, expressed as percent correct patterns reproduced, was decreased in a dose-dependent fashion by pentobarbital ($p < .025$).

The data of Figure 4 show that both speed and accuracy are sensitive dependent variables. The sensitivity of the automated DSST also has been revealed by preliminary results from studies currently in progress in our laboratory with relatively low doses of drugs administered to normal (i.e., nontolerant nonabuser) volunteers.

The response topography of the present automated version of the DSST is different from that of the paper-and-pencil versions. Direct comparisons of data obtained by the different versions should, therefore, be interpreted with caution. For example, mean scores obtained with a different automated version of the DSST were much lower than predicted on the basis of paper-and-pencil versions (Elwood & Griffin, 1972). In our experience, mean test scores following acquisition generally range between 35 and 55 correct in 90 sec. With paper-and-pencil versions of the test, higher (Bond & Lader, 1973; Schaeffer, Andrysiak, & Ungerleider, 1981), lower (McClain, Kromhout, Zieve, & Duane, 1981), and comparable (Eckhardt, Parker, Noble, Pautler, & Gottschalk, 1979; Kornetsky, 1951) scores have been reported under nondrug conditions. Of special relevance to this comparison are studies with the paper-and-pencil version of the DSST that showed not only scores comparable to those found using the present method, but similar acquisition curves for repeated administration as well (Wittenborn, Flaherty, McGough, Bossange, & Nash, 1976; Wittenborn, Flaherty, McGough, & Nash, 1979). Further research should provide direct comparisons of our automated DSST with paper-and-pencil versions, in terms of test-retest reliability, range of scores, and score distribution characteristics.

Figure 4. Effects of pentobarbital on the automated DSST performance of three subjects with histories of sedative abuse. Y-axis: Number of correctly reproduced geometric patterns (top panel) and percent correctly reproduced patterns (bottom panel). X-axis: Dose of pentobarbital (in milligrams) administered 2 h prior to testing. Data points show group means; brackets represent plus and minus standard errors of the means ($N = 3$).

The present report extends the work of Elwood and Griffin (1972), who automated the entire Wechsler Adult Intelligence Scale by means of tape decks, a Teletype, and digital logic, and the work of Ellinwood, Linnoila, Easler, and Molter (1981), who used a PDP-11/34 computer to require subjects to produce digits associated with test symbols. The present automated version of the DSST differs from previous automated versions in that the equipment is commercially available, relatively inexpensive, and portable. This version should prove useful for assessment of cognitive/psychomotor performance by researchers and clinicians from a wide variety of disciplines, including psychological assessment, behavioral medicine, neuropsychology, gerontology, and psychopharmacology.

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(Received for publication December 4, 1981;
revision accepted April 19, 1982.)