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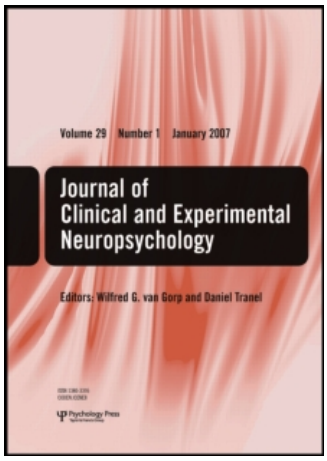

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Development and Validation of the Design Organization Test (DOT): A Rapid Screening Instrument for Assessing Visuospatial Ability

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Development and Validation of the Design Organization Test (DOT): A Rapid Screening Instrument for Assessing Visuospatial Ability

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A brief paper-and-pencil instrument was developed to rapidly assess visuospatial ability and serve as an alterative to the WAIS Block Design subtests during screening or when assessment time is limited. The Design Organization Test (DOT) consists of square black-and-white grids with visual patterns similar to those of the Block Design subtests. Administration is straightforward and requires examinees to reproduce as many designs as possible in 2 minutes using a numerical code key. For 411 college students, alternate forms of the DOT yielded reliability estimates comparable to that of the test-retest reliability of WAIS-III Block Design subtest. In a clinical sample, the DOT was significantly correlated (r = .92) with WAIS-III Block Design scores and was successfully substituted in place of Block Design raw scores without significant change in Performance IQ or Full Scale IQ. The results suggest that the DOT provides a useful and rapid screening measure of visuospatial ability.

The Wechsler scales are the most widely used tests of intellectual functioning (Daniel, 1997). The most recent publication of the 3rd Edition of the Wechsler Adult Intelligence Scale (WAIS-III) (Wechsler, 1997) includes 11 core subtests used in calculating Full Scale IQ. The Block Design subtest was retained in the recent revision virtually unchanged in any substantive way from previous editions of the Wechsler scales. This subtest presents patients with a set of plastic blocks, with two sides colored solid red, two sides colored solid white, and two sides bisected diagonally to form a red and a white triangle on each surface. Examinees are required to put the blocks together as quickly as possible to match an exemplar design presented in a stimulus booklet. Of all of the Performance subtests on the WAIS-III, the Block Design subtest has been found to have one of

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the highest loadings on the general intelligence factor "g" (Sattler & Ryan, 1998). Block Design scores also correlate highly with neuropsychological measures of visuospatial ability (Merten, 2002) and everyday visuospatial skills (Groth-Marnat & Teal, 2000).

Despite its strengths as a measure of visuospatial ability, there are some drawbacks to the Block Design subtest that make it difficult to use in certain settings. Because Block Design requires the use of fine motor skills to construct the designs, scores on the test may not provide the best assessment of visuospatial abilities for patients suffering from motor impairments. In such instances, other subtests such as Matrix Reasoning, which requires examinees to visually inspect colored design patterns and make a response choice, may provide a more valid assessment of visuospatial performance-related intellectual ability (Schoop, Herrman, Johnstone, Callahan, & Roudebush, 2001). Furthermore, comprehensive clinical neuropsychological assessments often require many hours of administration time, leading to fatigue in patients who are likely to have limited stamina due to their medical or neurological condition. Administration time for the WAIS-III may range from 60 to 90 minutes for healthy subjects (Wechsler, 1997), and can easily require over two hours for some clinical patients (Ryan, Lopez, & Werth, 1998). The Block Design subtest itself can easily exceed 15 minutes of administration time with some slower examinees. The need to gather more clinically relevant data in less time has led to an increasing emphasis on the development of short-forms of existing assessment instruments (Axelrod, Dingell, Ryan, & Ward, 2000; Donders, 2001; Kulas & Axelrod, 2002; Merten, 2002; Mount, Hogg, & Johnstone, 2002; Purdon & Waldie, 2001; Ringe, Saine, Lacritz, Hynan, & Cullum, 2002). Tests that can provide the same information about cognitive status or ability in significantly less time are likely to be preferred by patients, examiners, and third party payers alike (Donders, 2001). In addition, there are some occasions where examiners need only a brief screening instrument, or for practical reasons are not able to carry bulky testing equipment (e.g., multiple blocks, stimulus booklets).

To accommodate the need for a rapidly administered screening instrument for visuospatial ability, we developed a single-page paper-and-pencil assessment instrument designed to provide similar visuospatial information to that of the Block Design subtest in significantly less time and with less demand for fine-motor coordination or multiple pieces of equipment. This new instrument, the Design Organization Test (DOT), consists of 9 black and white square patterned grids similar in appearance, though not identical, to the WAIS-III Block Design stimuli. Below each design pattern is a grid of empty squares. A code key with 6 black and white squares and their corresponding numbers is placed at the top of the page. Examinees are required to reproduce the designs by writing in the corresponding numbers obtained from the key at the top of the page. In Study 1, we developed two alternate forms of the DOT and administered them to a large sample of college students to obtain fundamental reliability estimates. In Study 2, we administered the DOT to a sample of clinic patients presenting with a variety of neurological and psychiatric complaints during a neuropsychological evaluation. This second study permitted direct comparison of the DOT to the Block Design subtest of the WAIS-III to determine the new instrument's validity and clinical usefulness for assessing visuospatial ability.

Study 1: Item Development and Preliminary Assessment of Reliability

Overview

Two alternate forms of the DOT were prepared and administered to a large sample of undergraduate students in order to obtain estimates of reliability and to develop a preliminary normative database.

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Method

Subjects. Participants (n = 418) were recruited from a large undergraduate psychology course at the University of Pennsylvania and included 181 males and 237 females ranging in age from 17 to 27 years (M = 18.8, SD = 1.0). Participation was voluntary and no incentives were provided. Data were examined initially for outliers and it was determined that a few subjects demonstrated statistically atypical response patterns (i.e., obtained scores differing by more than 2.5 SDs in their relative performance on the two alternate versions of the test administered during the same session). These 7 subjects accounted for less than 1.7% of the total sample and were excluded from further analysis. This final sample (n = 411) included 179 males and 232 females ranging in age from 17 to 26 years (M = 18.8, SD = 1.0).

Materials. Two alternative forms of the DOT were developed. Each form included nine square designs (5 small designs and 4 large designs) comprised of smaller black and white squares and triangles (Figure 1 shows the sample practice item). Beneath each design was a response grid of identical size and shape (five 2×2 grids; four 3×3 grids), yielding a total of 56 response blanks on the form. At the top of each form was a response key consisting of 6 numbered squares (1 black square, 1 white square, and 4 squares that are half black and half white, divided along the diagonal in different orientations).

Procedure. Subjects completed the two alternate forms of the DOT as a large group in a lecture hall. Forms were administered in a counterbalanced order (i.e., 259 subjects received Form A first and Form B second; 161 subjects received Form B first and Form A second). A copy of the practice page of the DOT was displayed on an overhead projector as the investigator read the following instructions aloud:

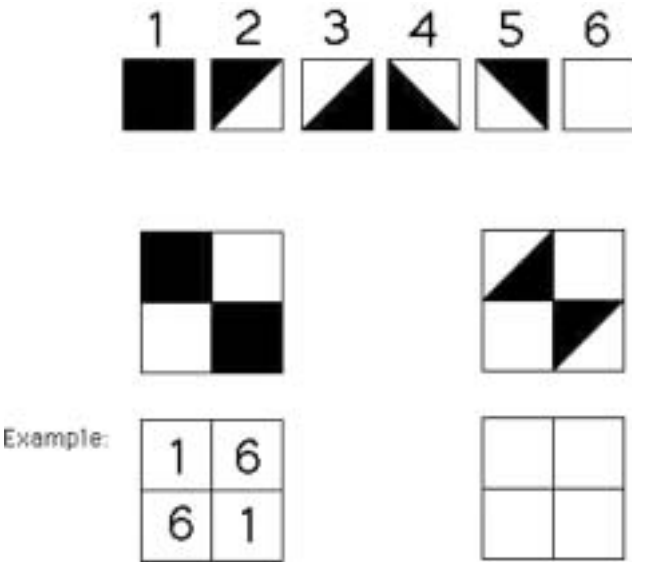

Figure 1. Code key and practice items given to examinees prior to administration of the DOT test page.

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> Look at these six boxes. Each box is different. Every box has a different design and has its own number from 1 to 6. Number 1 is solid black. Number 2 is half black and half white. So is number 3, but if you look closely, you'll see that the design for box number 3 is different from number 2. All six boxes are different, and each one has its own number.

The investigator then pointed to the example items below the key and read:

> Now look down here. This square design is made up of four of the boxes I just showed you. Down below are empty squares for you to put the numbers that match each box. This first one is already done for you. See, the first square is solid black. Look at the code key, the number for all solid black squares is number 1. So number "1" goes in this square. The lower right box is also black, so I also put a "1" in that square too. Here are two white boxes. See, the solid white boxes are always number 6, so the number "6" goes here and here.

The investigator then pointed to the next example item and said:

> Over here is a set of empty squares. See if you can match the design by filling in the code numbers. See, the first box is solid white. So what number would you put down here to match? Go ahead and complete the rest of the practice items.

Once the participants had completed the practice items, the investigator said:

> So all you have to do is put the correct number in each of the empty boxes to match the pattern above it. On the next page there are many designs much like the ones we just did. Look at each design and fill in as many of the empty boxes below it as you can with the correct numbers to match the designs. Do as many as you can. You will have only two minutes, so work as quickly as you can. Do you have any questions?

Subjects then worked for 120 seconds. At the end of the 120 seconds the examiner told the subjects to stop and put down their pencils. Subjects were then told that they would complete a second page in the same manner as the one they had just finished. Subjects were told to turn the page and begin. Again, subjects were given 120 seconds to complete as many of the 56 items as possible. There was no requirement for items to be completed in any particular order to be scored as correct. An item was counted as correct if its grid square contained a readable numeral that matched the corresponding correct item on the response key. The score was tallied as the total number of correctly completed response squares.

Results

Correlation Between Forms A and B. As an estimate of alternate forms reliability, the two forms were subjected to correlation analysis using Pearson's *r*. Overall the two forms were highly correlated with each other, $r = .80$, $p < .00001$, suggesting good alternate forms reliability. Furthermore, the strength of the correlation was not dependant on the administration order of the two forms (Fisher's r-to-z transformation, $z = 0.65$, ns), with

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the correlation obtained for Form A followed by Form B (r = .81) similar to the correlation obtained when Form B preceded Form A (r = .79).

Comparability of Mean Scores Between Forms A and B. When administered as the first form, there was no significant difference between the scores obtained from subjects taking Form A (M = 44.25, SD = 7.79) and those taking Form B (M = 43.61, SD = 7.83), t_{409} = 0.80, ns. When administered as the second form in the series, there was also no significant difference between groups taking Form A (M = 48.23, SD = 7.04) and Form B (M = 48.20, SD = 7.45), t_{409} = 0.05, ns. This suggests that the two forms provide comparable mean scores and are essentially identical in difficulty level.

Practice Effects. As expected for a psychomotor task, there was a significant practice effect between the administrations of the alternate forms within the same session, t_{410} = 17.93, $p < .001$. On average, the first administration of the DOT, regardless of form, resulted in an average of 44.00 (SD = 7.80) items correct, while the second administration yielded an average of 48.22 (SD = 7.19) items correct, an overall increase of 4.22 (SD = 4.77) units due to practice effects. For subjects administered Form A followed by Form B, the mean practice effect was 3.99 (SD = 4.62) units, t_{252} = 13.74, $p < .001$. Similarly, for subjects administered Form B then Form A, there was also a significant increase of 4.58 (SD = 4.99) units, t_{157} = 11.54, $p < .001$).

Discussion

Despite a large group administration with a homogenous student population from a competitive private university, the DOT had high alternate forms reliability. Furthermore, the two forms of the DOT yielded nearly identical mean scores and standard deviations when compared between groups at the same administration time. These data suggest that the DOT can be administered rapidly and that reliable data can be obtained using either version. The present data provide a preliminary normative database for further research and eventual application of the DOT in clinical settings.

Study 2: Validity and Clinical Utility

Overview

In order to establish its validity within a clinical setting, the DOT was administered in conjunction with a comprehensive neuropsychological test battery to a sample of patients with various types of neurologic illness. We hypothesized that DOT performance would be significantly correlated with performance on the Block Design subtest of the WAIS-III and that replacement of Block Design scores with a score derived from the DOT when calculating Performance and Full Scale IQ, would not lead to any significant change in either IQ score.

Method

Subjects. While undergoing a comprehensive neuropsychological evaluation at a large medical center in the Northeastern United States, 41 neurologic patients (23 male; 18 female) were administered the DOT in conjunction with a large battery of neuropsychological tests that included the WAIS-III Block Design subtest. A subset of these patients

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received the entire WAIS-III (n = 20) and/or enough of the Performance subtests to permit calculation of Full Scale and Performance IQ scores. The clinical sample included patients ranging in age from 18 to 76 years (M = 47.7, SD = 15.3), with an average of 14.6 (SD = 3.4) years of formal education. Because our aim was to examine the validity of the DOT in predicting Block Design scores regardless of diagnosis, and not to describe any particular neurologic condition, we made no effort to screen for particular disorders. Patient diagnoses included seizure disorder (n = 6), intracranial tumor (n = 6), dementia (n = 4), toxic/metabolic problems (n = 3), traumatic brain injury (n = 1), cerebrovascular accident (n = 6), demylinating disorder (n = 1), psychiatric or unclassified disorder (n = 14).

Materials and Procedure. Patients were tested individually and were administered the WAIS-III subtests in accordance with the standard instructions published in the test manual (Wechsler, 1997). Depending on the presenting medical condition, most patients received a number of other neuropsychological tests as well. To prevent any bias in actual clinical assessments, the DOT was always administered near the completion of the test battery, at least an hour after the WAIS-III. Patients were presented with Form A of the DOT and given the same general instructions as those described in Study 1. Patients were given a pencil and instructed to follow along as the examiner demonstrated the first practice item, which was printed on a separate sheet from the DOT test form (see Figure 1). The patient then completed the second practice item in front of the examiner. Patients were permitted to ask questions and were given further guidance and prompting if they appeared to be having difficulty completing the practice item. Once the practice item had been completed and all questions were answered to the patient's satisfaction, the patient was given the test form and timed for 120 seconds. There was no requirement for patients to complete the items in any particular order, but they were encouraged to complete as many items as possible within the two-minute time limit.

Results

Performance Assessment. Consistent with their status as neurologic patients, the participants in this study obtained a mean WAIS-III Block Design non-age corrected scaled score of 8.58 (SD = 3.71), which is significantly below the standard scaled score of 10, t_{40} = -2.44, p = .019, established by the normative group (Wechsler, 1997). On the DOT, patients obtained a mean score of 24.32 (SD = 12.75), which is significantly lower than the mean score for Form A obtained by the healthy college students in Study 1, t_{300} = 13.03, p < .001. This difference remained significant even when age was entered as a covariate between groups, $F_{1,297}$ = 4.04, p = .045.

Concurrent Validity. The scores on the DOT and the WAIS-III Block Design scaled scores (non-age corrected) were subjected to a Pearson correlation analysis. Scores on the DOT were highly correlated with those on the Block Design test, r = .92, p < .0001 (see Figure 2), suggesting that both tests measure similar visuospatial abilities and supporting the concurrent validity of the DOT. Scores on the DOT also correlated significantly with age (r = -.58, p < .001), but not with level of education (r = .13, ns). Even after removing the effects of age, however, the DOT remained highly correlated with the Block Design subtest, (partial r = .90, p < .0001). Table 1 summarizes the correlations between the DOT, Block Design, and other commonly used subtests of the WAIS-III.

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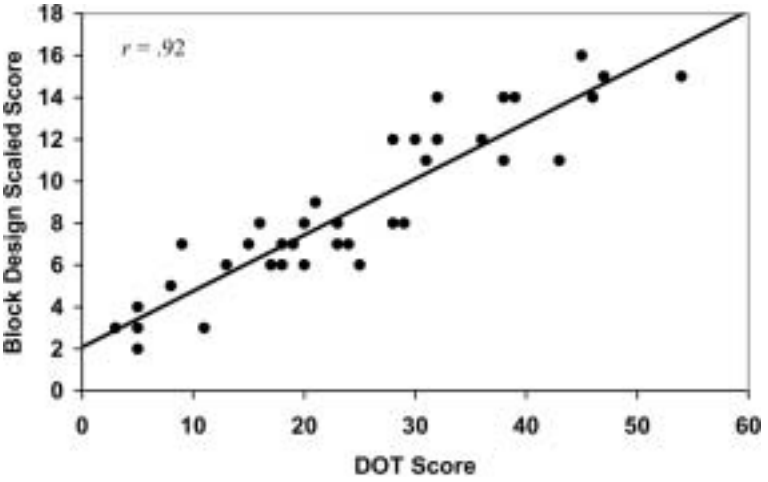

Figure 2. Scatterplot showing the linear relationship between DOT scores and scaled scores on the Block Design subtest of the WAIS-III.

Table 1
Correlations between DOT scores, Block Design scores, and Criterion measures of intelligence and mood

Criterion test	DOT	Block Design	*n* pairs
Age	-.58**	-.46**	41
Education	.13	.27	36
VIQ	.54**	.69**	23
PIQ	.74**	.86**	24
FSIQ	.66**	.82**	23
Block design	.92**	-	41
Information	.36	.51**	29
Digit span	.58**	.62**	36
Vocabulary	.40	.59**	23
Arithmetic	.62**	.74**	25
Comprehension	.44**	.59**	34
Similarities	.57**	.68**	23
Picture completion	.63**	.69**	29
Picture arrangement	.54**	.62**	24
Digit symbol	.68**	.59**	25
Beck Depression Inventory	.03	-.11	32
State anxiety	-.02	-.10	30
Trait anxiety	.15	.01	30

*$p < .05$, 2-tailed; **$p < .01$, 2-tailed.

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Discriminant Validity. The DOT was not expected to correlate with clinical variables unrelated to the theoretical construct of visuospatial ability. To test this, Pearson correlations were calculated between the scores on the DOT and three measures of mood given to most patients during the same assessment session. As expected, there was no correlation between the DOT and the Beck Depression Inventory (Beck & Steer, 1993) (r = .03, ns, n = 32), or the state (r = -.02, ns, n = 30) or trait (r = .15, ns, n = 30) components of the Spielberger State-Trait Anxiety Inventory (Spielberger, Gorsuch, & Lushene, 1970). These data are also summarized in Table 1.

Clinical Utility. Given the significant positive correlation between the DOT and the Block Design scaled scores, it was therefore of interest to determine whether the DOT could serve in lieu of Block Design raw scores when calculating WAIS-III Performance and Full Scale IQ scores. For this analysis, we replaced each subject's obtained block design raw score with an estimated raw score derived from their performance on the DOT. Specifically, scores from the DOT were entered into a linear regression analysis to estimate raw scores on the Block Design subtest (21 of the 41 patients had raw block design scores and complete WAIS-III data for calculating Performance and Full Scale IQ scores). Twenty-one separate regression analyses were conducted using a "leave-one-out" bootstrap procedure whereby each subject in the sample was temporarily excluded from the dataset and the DOT scores of the remaining 20 subjects were used to estimate Block Design scores. The regression equation obtained during each iteration was then used to predict the Block Design score of the excluded subject from that subject's own DOT score. All regression analyses were highly significant (all ps < .0001), with R^2 values ranging from 0.92 to 0.93. The estimated Block Design raw scores that were yielded by the regression equations were then substituted in place of the Block Design raw scores during a recalculation of Performance and Full Scale IQ scores. Replacement of actual Block Design raw scores with scores estimated from the DOT yielded Performance IQ scores that were nearly indistinguishable from those calculated with true Block Design scores, t_{20} = 1.10, ns. As evident in Figure 3, Performance IQ scores calculated using the DOT (M= 96.5, SD = 18.2) differed by approximately one-half a point from actual Performance IQ calculated in the standard manner using the Block Design subtest (M = 95.9, SD= 18.1). Similarly, Full Scale IQ using DOT scores in place of Block Design

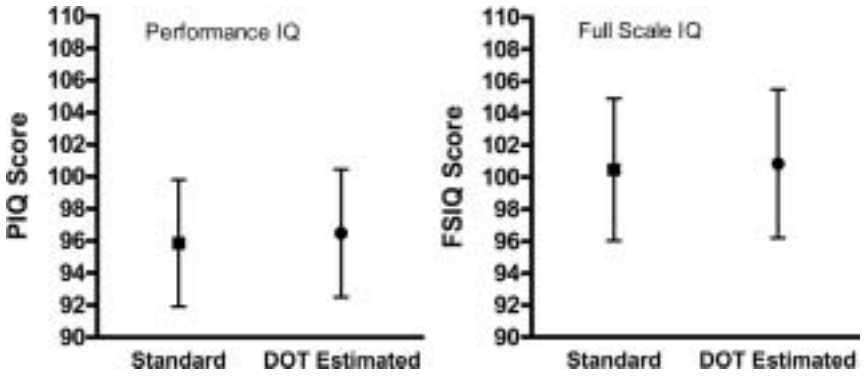

Figure 3. Mean IQ scores obtained by including the Block Design subtest in the standard manner and by substituting with DOT scores. (a) PIQ and (b) FSIQ scores were not significantly changed by substituting DOT estimated scores for Block Design scores.

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(M = 100.9, SD = 20.8) was nearly identical to Full Scale IQ calculated in the standard manner (M = 100.5, SD = 20.9; t_{19} = 1.16, ns).

Discussion. The present data support the validity of the DOT by demonstrating significant differences between high functioning college students and a sample of clinical neurologic patients. Concurrent validity was demonstrated by the very high correlation between the DOT and the Block Design subtest in a clinical sample. The DOT also demonstrated clinical utility by yielding nearly identical Performance and Full Scale IQ scores when substituted in place of the Block Design subtest in calculating these indices. Thus, the DOT appears to be a valid and clinically useful instrument for rapidly screening visuospatial ability.

General Discussion and Conclusions

In these two studies we described the development and preliminary validation of the DOT as a screening instrument for rapid assessment of visuospatial abilities. Overall, the DOT demonstrated good alternate forms reliability, effectively discriminated healthy subjects from clinical patients with neurologic complaints, and correlated highly with the Block Design subtest of the WAIS-III in the patient sample. Given that the DOT requires only two minutes of administration time, it can provide useful information about visuospatial ability in screening situations or when a clinician is faced with time constraints that prevent the administration of more extensive tests or batteries. In some situations, the DOT may serve as a preliminary visuospatial screen that can alert the examiner to the need for a more extensive evaluation with additional tests.

Estimation of reliability is critical in the development of a new instrument, but for timed tests such as the DOT, commonly used estimates of internal consistency such as coefficient alpha, are not appropriate (Nunnaly, 1978). In such cases, reliability is often estimated via the administration of alternate forms of the test during the same occasion or via repeated administrations of the same test on two different occasions. In Study 1, two forms of the DOT were developed and administered during the same session and were significantly correlated (r = .80) in a sample of high functioning college students. The alternate forms reliability of the DOT was comparable to the test-retest reliability reported for the Block Design subtest of the WAIS-III (r = .82) (Wechsler, 1997). Furthermore, there was no significant difference between the scores obtained on Form A or Form B, suggesting that they provide essentially the same information. Although the alternate forms reliability of the DOT was good, it may have underestimated the true reliability in the normal population due to the atypical nature of the student sample in Study 1. Participants were drawn from a highly selective private university with extremely competitive admissions standards, suggesting that the sample was biased toward the high end of the cognitive ability distribution. This homogeneous sample may have contributed to a lower correlation between the two forms by restricting the range of scores and by inflating the ceiling effect, as evidenced by the fact that 10.5% of these bright, well-educated participants achieved the maximum score on both administrations of the DOT. By contrast, the scores from the clinical sample in Study 2 were more evenly distributed and none of the neurologic patients achieved the maximum score on the DOT. These findings suggest that the correlation between the alternate forms in Study 1 represents a lower bound on the reliability estimate for the DOT.

A test cannot be valid if the data it provides are not reliable. Thus, another estimate of the lower bounds of reliability can be gained from the correlation between a new test and

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another test designed to measure the same theoretical construct (Nunnaly, 1978). In Study 2, we found that the scores of neurologic patients on the DOT were highly correlated (r = .92) with their scores on the Block Design subtest of the WAIS-III. The magnitude of this correlation suggests that the DOT measures abilities similar to those assessed by the Block Design test, supporting its validity as a measure of visuospatial ability and suggesting that the true reliability of the instrument should be at least as high as the obtained validity coefficient. Discriminant validity was also demonstrated in the clinical sample by the nonsignificant correlations with tests measuring mood-related constructs, such as depression and anxiety, which should be unrelated to visuospatial ability. Finally, the present results supported the clinical usefulness of the DOT as a potential alternative for Block Design in screening situations or when other factors limit the time or resources available for a comprehensive assessment. When DOT performance was used to replace Block Design raw scores in the calculation of Performance and Full Scale IQ there was no significant change in either of these IQ scores.

While these preliminary findings support the reliability, validity, and clinical usefulness of the DOT, there are a number of methodological limitations that require consideration. As mentioned above, the initial reliability study was conducted on a college student sample from a highly selective university and is not representative of the general population. Further development will be necessary with more diverse samples that include subjects from a broad range of cognitive ability and education level. Furthermore, the present validity analysis was limited to the sample of patients presenting with neurological complaints. Future research will need to evaluate the correlation between the DOT and visuospatial performance measures such as Block Design in a non-clinical population and with a wider range of cognitive ability instruments. Future studies will be needed to develop an adequate normative base and to evaluate the potential of the DOT to be completed with only verbal responses, removing the manual motor component completely. With the aforementioned limitations in mind, the present study can serve as a basis for further development and validation of the DOT as an alternative visuospatial assessment instrument that can be used in situations where patients have limited motor capacity, when a full assessment is not warranted, or when time constraints limit the amount of testing that can be performed.

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