Paper Title Preliminary Validation of a Spatial Ability Instrument for the Blind and Low Vision

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Abstract

Spatial ability is an intelligence that has been shown to be particularly important in science, technology, engineering, and math fields. Targeted spatial interventions have been shown to improve spatial ability and support the success of individuals in these fields. However, the blind and low vision community has largely been omitted from this research, in part because no accepted and validated assessment of spatial ability is accessible to this population. This paper describes the development and preliminary validation of a new spatial ability instrument that is designed to be accessible non-visually. Preliminary analysis indicates that the test has high reliability and validity.

Introduction

Spatial ability may be defined as the cognitive ability to generate, model, and interpret an object or space in the mind, and manipulate that model in some way. There are many constructs of spatial ability, such as cutting, rotation, folding, navigation, and perspective taking, although most measures of spatial ability assess only a subset of these constructs.

Research has found that spatial ability is a key intelligence (Gardner, 1983) that is predictive of future educational and vocational achievements in the fields of science, technology, engineering and math (Wai, Lubinski, & Benbow, 2009), and it has been demonstrated that spatial ability assessments would be a valuable addition to the battery of tests used to identify intellectually gifted students (Shea, Lubinski, & Benbow, 2001; Webb, Lubinski, & Benbow, 2007). In the field of engineering spatial ability has been found to be predictive of success in coursework and degree completion (Stieff & Uttal, 2015; Wood et al., 2016). Not only is spatial ability predictive of future performance, but it can be improved though targeted spatial interventions (Uttal, Miller, & Newcombe, 2013; Sorby, 2009b) and these improvements are maintained over time (Uttal, Miller & Newcombe, 2013), and support the same positive student outcomes as innate spatial ability (Sorby, 2009a).

Despite the importance of spatial ability, one group largely overlooked in this area is the blind and low vision (BLV) population. Spatial ability is often described in visual terms and assessed through visual means but it is fundamentally a cognitive process, and is not inherently dependent on vision. Understanding the spatial ability of BLV people[1] is just as valid and important as studying it in a sighted population. Since BLV people perceive information through non-visual means rather than relying primarily on vision, it is possible that they employ a unique set of spatial strategies and modalities (Cohen, et al., 2010) that could contribute to the overall understanding of spatial ability in all people.

One reason for this gap in the research is the lack of a non-visually accessible instrument to assess spatial ability. Even the limited research that has been done on the spatial ability of blind people generally uses self-designed spatial activities rather than a validated spatial ability instrument, see Leo et al. (2018).

According to Sorby (2009a), spatial ability tests commonly used in educational research to assess older children and adults include the Mental Cutting Test (MCT) (CEEB, 1939), the Purdue Spatial Visualization Test of Rotations (Guay, 1977), the Differential Aptitude Test: Space Relations (Bennett, Seashore, & Wesman, 1973), and the Mental Rotation Test (Vandenberg & Kuse, 1978). Each of these tests presents a two-dimensional perspective line drawing of a three-dimensional object either as part of the question prompt and/or answer choices. Although non-visual media, such as raised-line drawings or verbal descriptions, could be substituted for the print

[1] In this paper, we follow the disability language convention (i.e., identity first language) preferred by the blind community (National Federation of the Blind, 1993) instead of the person first convention that is commonly used in the field of education.

drawings, neither of these methods would effectively communicate all of the complexity, and detail of the three-dimensional shape. This constraint makes it impossible to translate any of these tests into a non-visual form without significantly altering the nature and delivery of the test.

The objective of this project is to develop and validate a spatial ability instrument that is fully accessible to those of all vision levels, in order to facilitate future research into spatial ability among BLV populations.

Test Development

The new test developed here, the Tactile Mental Cutting Test (T-MCT), is based upon the MCT (CEEB, 1939), but the questions and delivery of the test have been designed to allow for non-visual interpretation. The MCT was chosen because of its well-established validity and reliability, its longtime use in spatial ability research, its relative difficulty, and because of the spatial constructs of cutting, rotation, and proportion that are all present in the test (Call et al., 2016).

The MCT requires the test-taker to interpret a drawing of a three-dimensional block with a plane drawn through the block, and determine the shape of the cross-section created by cutting the block along the plane. An example problem is shown in Figure 1.

In order to make this question type non-visually accessible, the blocks shown in each problem stem of the MCT were modeled and 3D printed. Answer choices were developed as both large print and tactile graphics, scaled to match the 3D printed blocks. An example problem is shown in Figure 2. More information about the design of these questions can be found in a previous publication (Ashby et al, 2018).

Several logistical considerations of the test also had to be adjusted for the BLV population. Because tactile interpretation requires touching each part of an object or drawing and then synthesizing a model of the whole object, it can require more time than visual interpretation. Because of this, any time limit was dropped, and participants were allowed unlimited time to complete the test. In addition, the increased time required for tactile interpretation lengthened the test such that completing all 25 MCT questions was impractical without significant testing fatigue. To address this, the test was shortened to only 12 questions, and the bank of MCT questions was divided into two equivalent 12-question forms of the test.

Once a prototype of the T-MCT was designed, it was shown to groups of BLV individuals from blindness training centers to determine the most effective means of presenting the test to this population. In particular, feedback from the blindness community of practice influenced improvements in the size, texture, and materials of the questions, as well as the verbal directions, presentation of example problems, and administration protocol for the instrument.

Creating Equivalent Forms

To develop the equivalent forms, testing was conducted on all 25 MCT test problems. The procedures for this testing were reviewed and approved by an institutional review board to ensure ethical standards for research were met. In collaboration with the National Federation of the Blind (NFB), groups of BLV individuals were identified at blindness training centers, an NFB youth summer program, and a state NFB convention, and recruited to take the test. In some of these venues it was impractical to administer all 25 questions at once, so subsets of the test were administered and the data was aggregated. At the blindness training centers, 31 participants were each presented with all 25 questions. Nineteen of these participants completed all 25 questions, while the other 12 skipped one or more questions. The test could not be administered all at once during the summer program, so students were given a set of 9 problems when they arrived, and a set of 12 different problems a week later. Twenty-six students completed both pieces of the test, and an additional four completed one of the pieces. At the state convention 7 participants completed either all odd problems or all even problems. In total 68 BLV people participated and each problem was answered by at least 33 people.

These varied data sets were combined, and a difficulty index was calculated for each problem by dividing the number of correct responses by the total number of responses for that problem. Once the problems were ranked by difficulty index, one problem was removed because the difficulty index of that problem was a clear outlier compared to all other values, and there were an odd number of problems available. The remaining 24 ranked problems were allocated alternately to forms A and B. The average difficulty index of questions on form A was 0.538 with a standard deviation of 0.111, while the average difficulty index of the questions on form B was 0.521 with a standard deviation of 0.106, so the forms were considered sufficiently comparable.

Validation

Data Collection Methods

Another round of data was collected by administering forms A and B at an NFB summer program. Students were randomly assigned to take either form upon arrival at the program, and then took the alternate form several days later. In total, 22 students completed form A, and 22 students completed form B, with 21 students completing both. The average value of all student scores on form A was 67%, with a standard deviation of 26%. The average of all scores on form B was 65% with a standard deviation of 28%.

This set of data is used to determine the validity of this instrument as an appropriate measure of the test-taker's spatial ability.

Construct Validity

The T-MCT primarily derives its construct validity from its foundation in the MCT. The MCT has been used and accepted as a valid measure of spatial ability in research for many years (Sorby, 2009a). The form of questions in the T-MCT externalizes the rotation construct from a cognitive process to a physical process but the central spatial constructs of cutting, proportion, and scale, are fully retained.

Convergent Validity

Cronbach's alpha was calculated for each form in order to evaluate the internal consistency of the test. This value was found to be 0.8408 for form A, and 0.8405 for form B. According to the Statistical Associates Blue Book on validity and reliability (Validity, 2016 p. 413), a value of 0.8 or higher is considered a good reliability coefficient for confirmatory purposes.

In addition, the discrimination indices of each problem were calculated in order to identify any test items that were not valid or effective. These indices are presented in Table 1 in the appendix. All discrimination values were positive, with an average value of 0.49 in form A, and 0.55 in form B,

Finally, there was a correlation of 0.85 between students' results on form A and their results on form B. This finding supports both the equivalence of the two forms as well as the parallel forms reliability of the test.

Threats

Because the BLV community is a diverse group of people with varied levels of vision, light perception, and tactile proficiency, the T-MCT was designed to be used with either fully tactile or large print graphics. However the pilot data indicates that those who chose to use the large print graphics scored significantly higher than those who chose to use tactile graphics ($p < 0.001$). This indicates that test results may not be comparable between the tactile and large print versions, and these may need to be considered as separate instruments..

Another potential threat to the validity of the test is the fact that tactile information is interpreted at a lower resolution than visual information, and differences in line lengths or angles that are clear visually may not be clear tactilely. Since the original MCT answers were designed only to be visually distinguishable, some problems have only slight differences between the correct and incorrect answers, which may not be tactilely distinguishable. Further work will be done to ensure that all incorrect answer choices are sufficiently distinct from the correct answer choices so that the tactile graphics user can discern the differences.

Conclusion

This preliminary analysis of the validity of this instrument demonstrates that it holds great potential as a spatial ability assessment among BLV populations. The development of this test is still a work in progress, and more data is still being collected for refinement and validation. The research team is continuing to collaborate with the NFB in the validation, use, and dissemination of this new instrument.

Appendix: Figures and Tables

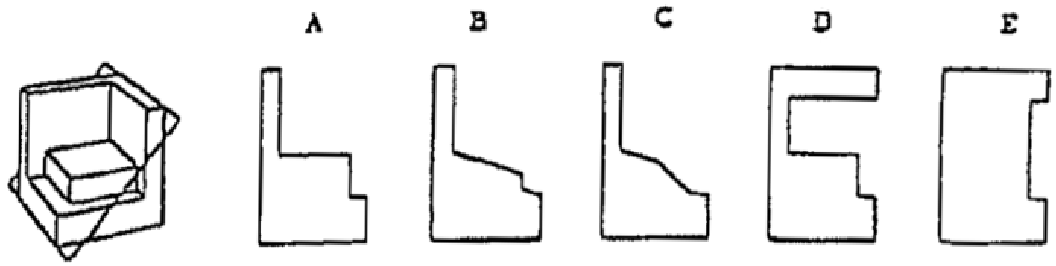

Figure 1: MCT Example problem

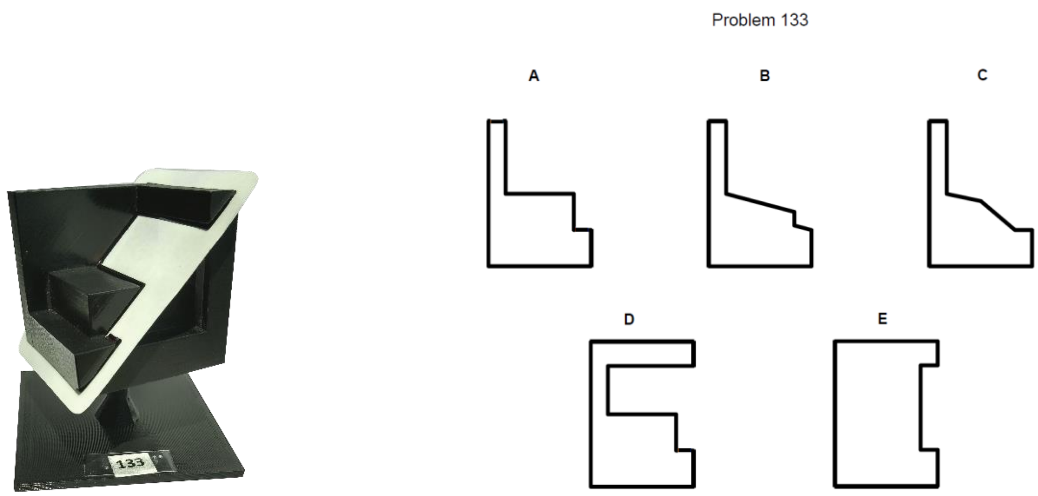

Figure 2: T-MCT Example problem. Large print answer choices are shown here, but embossed tactile graphics with braille labels are also used.

Table 1: Discrimination indices of all T-MCT items

Problem	1	2	3	4	5	6	7	8	9	10	11	12
Form A	0.44	0.44	0.56	0.89	0.44	0.11	0.33	0.78	0.11	0.89	0.22	0.67
Form B	0.56	0.67	0.44	0.56	0.33	0.67	0.67	0.56	0.44	0.67	0.33	0.67

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