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Work in Progress: Exploring Reliability of the Tactile Mental Cutting Test in Assessing Spatial Abilities Among Native American Children

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Abstract

Spatial ability is one of the vital cognitive skills that is linked to success in education and different fields, especially in the STEM (science, technology, engineering and mathematics) field. The term refers to the mental capability of visualizing and manipulating objects around you in space, which is vital in solving engineering problems and the resulting learning outcomes. Despite their importance, spatial assessment tools application to a variety of underrepresented populations, such as Native American students, remains limited.

Several different instruments such as Mental Cutting Test (MCT), Mental Rotation Test (MRT), Purdue Spatial Visualization Test: Rotations (PSVT: R), Differential Aptitude Test are developed to measure spatial ability. Each instrument has been used for quite some time and research has been published establishing the instrument's validity and reliability. A newer tactile spatial ability instrument, the TMCT, has recently been developed and applied as an accessible instrument for assessing spatial ability in blind and low vision populations. This instrument's incorporation of a tactile component sets it apart from others. The TMCT was modified from the MCT(CEEB,1939). Research has shown it to be a valid and reliable instrument. Recent work has been conducted to expand the use of this instrument into other demographics. This study investigates initial reliability research for the application of the Tactile Mental Cutting Test (TMCT) for Native American elementary age students. Reliability estimates are reported for the two subtests of the TMCT.

Preliminary findings indicate that TMCT exhibits good reliability with the Native American students sampled and that more sampling is needed. The TMCT's demonstrated reliability emphasizes its importance in spatial evaluations. Future study should investigate the TMCT's broader applicability and impact on educational achievements in Indigenous populations, enhancing the discussion of equitable assessment techniques in STEM education.

Introduction

The cognitive ability to comprehend, visualize, and work with things and their spatial relationships in two and three dimensions is known as spatial ability. According to[1], spatial ability includes several concepts, including spatial perception, mental rotation, spatial visualization, and spatial interactions. Everyday actions like navigating, putting things together, and deciphering schematics require spatial abilities [2]. Spatial ability has been divided into several subcategories by [3], such as mental rotation and spatial visualization, which vary in complexity and use. Significant differences in spatial ability are influenced by age, training, and gender[4]. A recent meta-analysis of children aged 0–8 years shows early spatial interventions, like hands-on and gestural activities, effectively enhance skills such as mental rotation and perspective-taking, highlighting the value of spatially enriched early education[5]. According to [6], these abilities are also essential for the development of spatial reasoning, which promotes creativity and problem-solving in technical domains.

Because spatial ability supports vital abilities like creativity, problem-solving, and visualization, and due to its correlation with success in STEM (science, technology, engineering and mathematics) majors and fields [7] spatial ability is seen to be a fundamental component of success in STEM education. High spatial ability has been linked to improved scholastic achievement in STEM fields, such as mathematics, physics, and engineering [7], [8]. Spatial skills are predictive of STEM career persistence, especially in occupations that need strong visualization skills[9] . According to [10], spatial ability is malleable skill suggesting that training could bridge performance disparities for underrepresented groups in addition to being a predictor of STEM success. According to [11], spatial ability enhances verbal and mathematical reasoning and makes a distinct contribution to creative problem-solving in STEM fields. Additionally, it has been demonstrated that multidisciplinary approaches that incorporate spatial training into STEM courses improve understanding and creativity [12].

Targeted interventions and training programs can greatly improve spatial skills, which are not static. Spatial reasoning is flexible, according to meta-analyses, and interventions can provide long-lasting gains, particularly in younger children who may benefit more due to sensitive developmental periods[1]. Studies done by [13]with participants aged 18–43, show improvements across tasks, underscoring the importance of age in training outcomes. The effectiveness of a spatial vision training program in raising engineering student performance highlights the importance of such programs in STEM education. The study notes that spatial ability assessed during adolescence (e.g., age 13) is a significant predictor of later success in STEM fields, demonstrating the relevance of early interventions in fostering these critical skills [8].Furthermore, demonstrating the cross-disciplinary advantages of spatial training,[14]discovered that it helps students in mathematics, especially geometry. [15] shown that even brief interventions, such solving spatial puzzles and building blocks, result in quantifiable improvements in spatial cognition. Spatial training is an important area of focus for educators and policymakers because of the possibility for scaling these interventions to address inequities in STEM performance [12].

Numerous tools have been created to evaluate spatial ability, each focusing on a distinct aspect of spatial reasoning. Developed by Vandenberg and Kuse in 1978, the Mental Rotation Test (MRT) assesses the capacity to mentally move three-dimensional objects. Particularly in engineering education, the Purdue Spatial Visualization Test (PSVT) evaluates spatial visualization abilities [16]. The Paper Folding Test (PFT), another instrument, assesses a person's capacity to envision the outcomes of folding paper [17]. The Santa Barbara Solids Test (SBST), which focuses on challenging three-dimensional spatial tasks, is one of the more recent developments [2]. The variety of spatial testing capabilities has been further increased by the introduction of digital technologies, such as assessments based on virtual reality [18]. Every tool is essential to the evaluation process. Each instrument plays a critical role in evaluating spatial reasoning in both research and practical applications.

The Tactile Mental Cutting Test (TMCT) uses hands-on methods to assess spatial aptitude, offering a real-world approach compared to traditional tests like the Mental Rotation Test (MRT). Research shows tactile assessments are effective for evaluating kinesthetic learners' spatial reasoning strengths[19]. TMCT also complements visual-based evaluations by providing a deeper understanding of spatial abilities[6], ensuring wider accessibility and applicability for diverse populations in STEM education.

Methods

Originally created in 1939 as a component of the College Entrance Examination Board's (CEEB) Special Aptitude Test in Spatial Relations, the MCT served as the model for the TMCT. The MCT assesses spatial vision abilities using two-dimensional isometric drawings of three-dimensional objects with intersecting planes [20]. To make the test more accessible, the TMCT transformed these visual elements into tactile representations. Computer-Aided Design (CAD) software was used to design three-dimensional items, which were subsequently 3D printed to produce tangible models as part of the development process [21]. Cutting planes were depicted on laminated paper so that participants could sense the planes' junction and direction. This physical modification allowed for non-visual exploration while maintaining faithfulness to the original MCT. To cut down on the amount of time required to finish the test, the TMCT test is divided into two subtests, A and B, each with 12 questions and the same degree of difficulty. To guarantee accessibility, comfort, and equity for all participants, especially those with visual impairments, the Tactile Mental Cutting Test (TMCT) was administered in a controlled and organized setting.

Figure 1. Example 3-D TMCT item[22]

Participants took the Tactile Mental Cutting Test (TMCT) on a revolving turntable, allowing easy access to objects without adjusting posture. They used a tablet to select answers, with five possible cross-sectional shapes for each test object. Standardized instructions were read aloud by a proctor, who provided assistance as needed. Unlike the original Mental Cutting Test, TMCT had no time limit, to attempt to reduce stress and improve accuracy. The testing environment was distraction-free to help participants focus.

Population

The participants in this study were students attending elementary schools in several neighboring rural communities. A total of 38 Native American students, aged between 3 and 12 years, participated in the research. A large span of age was considered acceptable given the nascent nature of these instruments used with different age groups and each location’s smaller participant numbers.

Descriptive Statistics

Participants were given Subtest A or B based on the elementary school location. So, 23 participants took Subtest A, and 15 participants took Subtest B. The participants in this test belong to varying age groups. Specifically, there is 1 participant aged 3, 26 participants between the ages of 5 and 8, and 11 participants between the ages of 9 and 12. For Subtest A, the mean and standard deviation of percent of items correct is found to be 64.78% and 25.91% respectively while for Subtest B, the mean and standard deviation of percent of items correct is 44.00% and 23.84% respectively.

Table 1. Descriptive Statistics for Subtest A and B

	Mean	Standard Deviation
Subtest A	64.78%	25.91%
Subtest B	44.00%	23.84%

Reliability Analysis

This statistical technique evaluates a measurement scale's reliability and consistency. It assists in determining whether a test or measurement instrument yields reliable and consistent results after several uses. Internal consistency testing utilizing Cronbach's alpha of the A and B components using correlation and means and variance comparison were both part of the reliability analysis that was carried out. For each of the subtest TMCT questions were analyzed using Cronbach's alpha coefficient. For subtest A Cronbach's alpha was found to be 0.66 signifying good reliability. While it's above the commonly accepted threshold of 0.60 for exploratory research, it is possible that there may be some inconsistencies in the items within Subtest A. Subtest B had a value of 0.60, which is equal to the threshold, indicating moderate reliability. A summary table of those results is provided below.

Table 2. Internal Consistency of TMCT for Subtest A and B

	Cronbach's Alpha	Sample size
Subtest A	0.66	23
Subtest B	0.60	15

Cronbach's alpha values for the Tactile Mental Cutting Test (TMCT) reliability were 0.66 and 0.60, suggesting moderate reliability. An inadequate sample size, developmental differences among elementary school students, and potential design issues may have affected the results. These findings highlight the need for further research with larger samples, improved test design, and better validity checks to enhance the instrument's effectiveness in assessing spatial ability.

Conclusion

The TMCT appears to have moderate reliability in measuring spatial constructs like rotation, cutting plane, and proportion among elementary school students, according to preliminary computations. These results suggest that the TMCT has potential as a tool for evaluating spatial ability in younger populations, even though dependability ratings of 0.66 and 0.60 fall within the generally recognized threshold. The results make the case for the instrument's ongoing development and improvement to increase its dependability and relevance. The TMCT was first created for a particular group, but it has potential as a platform for more extensive studies on spatial ability in a variety of demographics as well as a reliable instrument for assessing spatial ability among Native American students.

Future Work

To improve the Tactile Mental Cutting Test's (TMCT) validity, reliability, and usefulness, future research should concentrate on a few important aspects. Increased sample size and participant diversity will yield more reliable dependability estimates and enhance the findings' generalizability. By streamlining instructions and standardizing tactile elements, the test design can be improved to better match the target population's cognitive and developmental stages. To make sure the TMCT evaluates spatial constructs including rotation, cutting plane, and proportion appropriately, more validity studies—such as concept and criterion validity—are necessary. The test's stability over time might be further investigated through longitudinal research, and its application could be expanded by investigating how well it adapts to different populations, such as sighted people or people with different sensory needs.

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