TECHNOLOGY MEDIATED ASSESSMENT OF DYNAMIC SPATIAL ABILITY

J. Buckley[1], C. O'Neill[1] and N. Seery[1]

1. Department of Design and Manufacturing Technology, University of Limerick, Ireland.

ABSTRACT

The role of spatial ability in STEM educational performance has been substantially illustrated since the inception of this research agenda. However, studies which have identified this relationship typically do so using static measures of performance. It is posited that dynamic spatial ability may align more with the dynamic environment in which humans must negotiate however technological limitations have constrained the capacity to test this faculty.

Building on past studies of dynamic spatial ability, the aim of this study was to initiate the creation of psychometric tests for dynamic spatial factors. The findings suggest a gender difference favouring males which aligns with results regularly cited using static measures and a number of considerations for future psychometric developments in this area are offered. It is envisioned that the development of these tests could aid in ascertaining the role of dynamic spatial ability in STEM education and subsequently assist in the direction of associated future educational developments.

KEYWORDS: Dynamic Spatial Skills, Visual Perception, New Technologies

1. INTRODUCTION

Spatial ability "is a multifaceted component of intelligence that has predictive validity for future achievement in science, technology, engineering and maths (STEM) occupations" [1] and substantial research has established its association with STEM educational success [2, 3]. However it is acknowledged that the psychometric factor structure of spatial ability may not yet be ultimately defined [4, 5]. An important aspect of spatial ability which merits further investigation in this area is that of dynamic spatial ability as Larson [6] notes that there may be a poor association between static spatial tests and the dynamic environment which humans inhabit and must negotiate.

Early work in the area of dynamic spatial ability began with a military focus [7, 8]. Since then this has evolved into the broader domain of human intelligence where an agenda exists to elicit the scope of human cognitive abilities. Subsequent to the work of Roff [7] and Gibson [8] the concept of dynamic spatial ability was further investigated by Hunt and Pellegrino [9, 10, 11] and this work provided a basis for two factor-analytic studies [12, 13] which were carried out to determine if dynamic spatial reasoning was distinguishable from static spatial reasoning. The results of both studies suggested the validity of this bifurcation. Synthesising this work, Buckley and Seery hypothesised a spatial ability framework inclusive of a number of dynamic spatial factors containing both spatial skills and perceptual factors [14, 15], however empirical evidence is needed to validate their existence as unique cognitive factors. Larson's [6] argument suggests this agenda as being particularly important for STEM education due to the overwhelming evidence of the importance of spatial ability in this domain. The lack of research in this area can be attributed to technological limitations preventing authentic test design. However, due to technological advances both in terms of the capacity of technologies and access to technology, there is a need to establish tests to validly determine the remit of this cognitive domain. Such tests would aid in empirically establishing the role of dynamic spatial ability in STEM education and aid in the construction of associated education interventions. Therefore, the aim of this study was to initiate the experimental design of dynamic spatial ability test instruments.

2. METHOD

2.1. Approach and Participants

As this study aimed to explore the use of new technologies in dynamic spatial ability assessment, multiple technologies were implemented including video, Microsoft PowerPoint presentations and augmented reality (AR). The technologies were utilised to create experimental psychometric assessments for both dynamic spatial skills and dynamic spatial perception. The perceptual factors included in this study were *dynamic serial perceptual integration* (DSPI) and *movement detection* (MD) and the dynamic spatial skills factors included *directional judgement* (DJ) and *speed judgement* (SJ). Due to the nature of the technologies and test design, tests needed to be administered individually to participants within the cohort (n=30). The study cohort consisted of 15 males and 15 females. The mean age was 21.23 with a standard deviation of 1.17. The participants consisted of undergraduate university students from a variety of disciplines including Materials and Architectural Technology (n=12), Materials and Engineering Technology (n=4), Physical Education (n=4), Physiotherapy (n=3), Science Education (n=2), Civil Engineering (n=2), History, Politics and Social Studies (n=1), Business Studies (n=1), and Irish Music and Dance (n=1).

2.2. Design and Implementation

For this study five unique tests were designed. One test was created for each of the factors except for speed judgement for which two alternative versions were explored. Descriptions of each test are offered below:

- ***Speed Judgement 1***: In this test the participant is presented with two horizontal paths, each containing a circular dot and a vertical goal line. Both dots move along their respective paths at different speeds towards the goal lines. As the dots move they both disappear together after a specific distance. The participant has to identify which dot would hit the respective goal line first. The test contains 20 items which systematically increase in difficulty through variations in speed and dot visibility time. Each item is scored as either correct or incorrect.

- ***Speed Judgement 2***: In this test the participant is presented with one path containing a circular dot and a goal line. The dot moves along the path at a constant speed towards the goal line. As the dots moves it disappears after a specific distance. The participant has to identify when dot would hit the goal line. The test contains 20 items which systematically increase in difficulty through variations in speed, path length and complexity, and dot visibility time. Each item is scored as the variance between the time when the dot would reach the goal line and the participant's response.
- ***Directional Judgement***: In this test the participant is presented with a 3-dimensional (AR) environment. The environment contains a series of goals in different positions. The AR environment is positioned over a flat table. A ball is fired is a specific direction and is visible until it reaches the AR environment. The participant has to identify which of the goals the ball would reach. The test contains 30 items which systematically increase in difficulty through variations in speed and ball visibility time. Each item is scored as either correct or incorrect.
- ***Movement Detection***: In this test the participant is presented with a white screen divided into four quadrants by a vertical and horizontal line. A circular dot is located in each quadrant. One or multiple dots will move either vertically or horizontally. The movement is at varying slow speeds and over short distances. The participant has to identify which of the dots move and in what direction. The test contains 20 items which systematically increase in difficulty through decreases in speed and increases in the number of moving dots. Each item is scored depending on the number of correct movements identified.
- ***Dynamic Serial Perceptual Integration***: In this test the participant is presented with a white screen. A circular dot appears in the centre of the screen and makes one of 8 movements. Movements are restricted to the directions of vertical, horizontal and 45°. The movement occurs at varying speeds and the visibility time of the dot decreases at regular intervals (1500ms to 10ms). The participant has to identify the direction of the movement. The test contains 36 items which systematically increase in difficulty by decreases in the length of time the dot is visible for. Each item is scored as either correct or incorrect.

Each participant completed the tests in a different order to control for order bias. With the exception of directional judgement, the implementation of each test was identical. A chin rest was used to ensure a consistency in test design with the stimuli measuring 8° x 8° of the participants' visual field which aimed to control inferences made due to perceptual differences as a result of motion parallax. Tests were created in black and white to control for potential variances in colour vision. As the directional judgement test was designed using AR, the set up did not permit a consistency in administration with the other tests. However, consistency in test administration was controlled at an individual level.

3. FINDINGS

As this study describes the initial stages in the development of psychometric tests, ascertaining reliability is critical to guide further developments. The following Cronbach's Alpha values were determined for each of the tests; SJ1 (α = 0.327), SJ2 (α = 0.943), DSPI (α = -0.122), MD (α = 0.760), DJ (α = 0.765).

The first major insight offered by these results is the difference in reliability between SJ1 and SJ2. It is posited that this is due to the scoring mechanism within the tests. While SJ1 was scored on a binary decision, SJ2 was more accurate by capturing the variance between the actual arrival time and the participant response. The low and negative alpha value for DSPI is posited to be a result of many test items being outside the scope of the human perceptual system. Out of the 36 test items, 22 had a correct response rate lower than 50%. Where the movement occurred across a distance of 4°, response rates were lower than 50% when visibility time was 420ms and below. Where the movement occurred across a distance of 2°, response rates were lower than 50% when visibility time was 190ms and below. Finally, where the movement occurred across a distance of 0.1°, response rates were lower than 50% when visibility time was 200ms and below. Thorpe et al [16] determined that humans could accurately process static visuals when presented for 20ms. In this study, it is posited that the dynamic nature of the stimuli caused the variance in time.

Subsequent to examining the reliability of the tests, a correlational analysis was conducted to examine any potential associations between tests (Table 1). Four statistically significant correlations are observable however only the correlation between MD and DJ is of moderate strength (r = .405, p = <0.05). This may stem from a need for visual acuity in both tests.

Table 1. Correlation matrix for dynamic spatial ability test results

	Directional Judgement	Dynamic Serial Perceptual Integration	Speed Judgement 1	Speed Judgement 2
Dynamic Serial Perceptual Integration	.337			
Speed Judgement 1	-.366*	-.189		
Speed Judgement 2	.380*	-.187	.006	
Movement Detection	.405*	.242	-.231	.366*

*. Correlation is significant at the 0.05 level (2-tailed).

The final analysis was conducted to identify any potential gender differences across the test battery. A series of independent samples t-tests were conducted to identify any statistically significant differences. The results (Table 2) illustrate that males outperformed females in all tests except SJ1. Considering the low levels of reliability for this test, these results appear to align with the regularly cited gender difference favouring males found in static tests [17, 18]. Interestingly, there is only negligible variance in the mean scores for the DSPI test (0.001%) which may suggest a similarity in perceptual abilities across males and females.

Table 2. T-test results examining gender differences across the test battery

Measure	Male		Female		*t*	*df*	*p*
	Mean	Std. Deviation	Mean	Std. Deviation			
DJ	69.777	12.754	54.889	16.944	2.719	28.000	.011
DSPI	44.630	3.395	44.629	3.992	.001	28.000	.999
SJ1	75.333	9.537	78.667	9.722	-.948	28.000	.351
SJ2	87.200	2.731	81.933	7.583	2.531	17.572	.021
MD	84.000	10.212	66.667	16.762	3.420	23.135	.002

4. DISCUSSION AND CONCLUSION

The results of this study suggest merit in the progression of this research agenda. Critically, it is clear that psychometric tests can be developed and administered which contain moving visual stimuli with existing technologies. In terms of generating these tests, a number of considerations have emerged such as the need for consistency in administration, the use of appropriate scoring mechanisms to capture individual variances, and the need to elicit and cater for the capacity of the human perceptual system. In addition to these, the current tests could have been enhanced. For example, a reaction time analysis should be incorporated into the tests for SJ and while perceptual limitations were uncovered in the DSPI test, the same should have been done for slow and small movements in the MD test.

While these results are of significant interest in the general field of human intelligence, for STEM education they aid in the advancement of dynamic spatial ability integration. Using these results, a new battery of tests can be developed which cater for the entire remit of dynamic spatial factors which can be correlated with measures of STEM performance to determine if there is a significant relationship and where to focus pertinent educational developments.

5. REFERENCES

[1] L. Andersen, Visual-Spatial Ability: Important in STEM, Ignored in Gifted Education, *Roeper Review*, Vol.36 (2014), 114–121.

[2] D. Lubinski, Spatial ability and STEM: A Sleeping Giant for Talent Identification and Development, *Pers. Individ. Dif*. Vol.49 (2010), 344–351.

[3] J. Wai, D. Lubinski, and C. Benbow, Spatial Ability for STEM Domains: Aligning over 50 years of Cumulative Psychological Knowledge Solidifies its Importance, J. Educ. Psychol. Vol.101 (2009), 817-835.

[4] J. Carroll, *Human Cognitive Abilities: A Survey of Factor-Analytic Studies*, Cambridge University Press, New York, (1993).

[5] J. Schneider and K. McGrew, The Cattell-Horn-Carroll Model of Intelligence. in D. Flanagan and P. Harrison (eds.). *Contemporary Intellectual Assessment: Theories, Tests, and Issues*, Guilford Press, New York, 2012, 99–144.

[6] G. Larson, Mental Rotation of Static and Dynamic Figures, *Percept. Psychophys.* Vol.58 (1996), 153–159.
[7] M. Roff, A Factorial Study of Tests in the Perceptual Area, *Psychom. Mon*. Vol.8 (1952), 1–41.
[8] J. Gibson, *Motion Picture Testing and Research*, Government Printing Office, Washington DC, (1947), AD 651783.
[9] E. Hunt, J. Pellegrino, R. Frick, S. Farr and D. Alderton, The Ability to Reason about Movement in the Visual Field, *Intell*. Vol.12 (1988), 77–100.
[10] J. Pellegrino and Hunt, Computer-Controlled Assessment of Static and Dynamic Spatial Reasoning, in R. Dillon and J. Pellegrino (eds.). *Testing: Theoretical and Applied Perspectives*, Praeger Publishers, New York, 1989, 174–198.
[11] J. Pellegrino, E. Hunt, R. Abate and S. Farr, A Computer-Based Test Battery for the Assessment of Static and Dynamic Spatial Reasoning Abilities. *Behav. Res. Meth. Ins. C*. Vol.19 (1987), 231–236.
[12] J. M. Contreras, R. Colom, J. M. Hernández and J. Santacreu, Is Static Spatial Performance Distinguishable from Dynamic Spatial Performance? A Latent-Variable Analysis, *J. Gen. Psychol*. Vol.130 (2003), 277–288.
[13] T. D'Oliveria, Dynamic Spatial Ability: An Exploratory Analysis and a Confirmatory Study. *Int. J. Aviat. Psychol*. Vol.14 (2004), 19–38.
[14] J. Buckley and N. Seery, Framing Spatial Cognition: Establishing a Research Agenda, in L. Sun, H. Steinhauer and D. Lane (eds.). Proc. ASEE EDGD 70th Mid Year, Daytona Beach, Florida, 2016, 118–122.
[15] N. Seery, J. Buckley and T. Delahunty, Developing a Spatial Ability Framework to Support Spatial Ability Research in Engineering Education, in B. Bowe (ed.). *Proc. 6th REES*, Dublin, 2015.
[16] S. Thorpe, D. Fize and C. Marlot, Speed of Processing in the Human Visual System, *Nature*, Vol.381 (1996), 520–522.
[17] M. Linn and A. Petersen, Emergence and Characterization of Sex Differences in Spatial Ability: A Meta-Analysis, *Child Dev*, Vol.56 (1985), 1479–1498.
[18] S. Sorby, *Educational Research in Developing 3-D Spatial Skills for Engineering Students*, Int. J. Sci. Ed. Vol.31 (2009), 459–480.