The Potential Bifurcation of Static and Dynamic Spatial Cognitive Processes

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Abstract

Considering the widely acknowledged correlation between spatial ability and graphics based education, it is important to uncover the full remit of this association to inform pedagogical practices within the discipline. One aspect of this relationship which has yet to be explored is the role of dynamic spatial reasoning in graphical education performance. However, to instigate an investigation of this nature the scope of this cognitive domain merits further establishment. This study presents an initial investigation into this area with the aim of examining the potential bifurcation of established spatial factors into a dynamic and static dichotomy. A cohort (n=15) of undergraduate and postgraduate students completed 8 tests of spatial ability spanning 4 unique factors. Three of the tests were experimental measures. Findings from a correlational analysis provide insight into the nature of dynamic spatial reasoning while a reliability analysis offers suggestions for test refinement.

Introduction

The cognitive faculty of spatial ability is widely recognized as being multifactorial, consisting of factors associated with visual memory, visual perception, and spatial skills of cognitive speed and power (Buckley & Seery, 2016; Carroll, 1993; Horn & Blankson, 2005). Considering the consistently cited correlation between spatial skills and graphics education (Marunic & Glazar, 2013) it is therefore important to consider the potential position that additional spatial factors may have on determining success within this field.

One area of spatial cognition which has yet to be explored in relation to graphics education is the area of dynamic spatial ability. There are two schools of thought on dynamic spatial thinking. One categorization relates to the nature of the cognitive action whereby mental operations such as mental rotations would be considered dynamic (Newcombe & Shipley, 2014) while the other considers dynamic reasoning to involve moving stimuli and is independent of the cognitive action (Pellegrino, Hunt, Abate, & Farr, 1987).

The classification of dynamic spatial ability as involving moving stimuli is more commonly accepted. This may be associated with biological evidence identifying neurons as responsive to selective stimuli (Groh, 2014). For example, Hubel and Wiesel (1959) identified single neurons as responsive to stimuli orientation while Haag and Borst (2004) describe specific motion sensitive neurons. This identification corroborates the argument presented Larson (1996) who posits that static spatial ability is not representative of environments in which humans operate as they are embodied by dynamic stimuli. Pellegrino et al. (1987) further note that the sole use of paper and pencil tests limits explorations of this domain.

While the evidence supporting the existence of a dynamic spatial reasoning as dissociable from static reasoning is limited, a number of factor analytic studies suggest that this may be the case (Contreras, Colom, Hernández, & Santacreu, 2003; D'Oliveria, 2004). However, while research to date has focused on identifying unique dynamic factors, the potential bifurcation of validated static factors into a static-dynamic dichotomy has not yet been explored. If dynamic reasoning is going to be examined for a potential link to graphical education, this relationship must first be examined. In order to achieve this, it is first necessary to develop a set of appropriate methodological tools. Therefore, the primary purpose of this study was to create a series of experimental psychometric tests capable of validly eliciting dynamic cognitive capacities.

Method

To instigate the investigation into this potential bifurcation of spatial factors, four factors were selected for inclusion which related to memory (visual memory), perception (perceptual alternations) and spatial skills (perceptual speed and spatial scanning). These were selected as many factors do not facilitate a dynamic alternative. For example, adding movement to a stimulus aiming to espouse mental rotation capacities would circumvent the need for cognitive mental rotations, a limitation coinciding with the cognitive operations classification of dynamic spatial reasoning. Static and dynamic tests were administered to the cohort for each factor. For the perceptual alternations factor two validated stimuli were utilized; the Necker cube (e.g. Ishizu & Zeki, 2014) and Thurstones Windmill (Thurstone, 1944), while established static psychometric tests were utilized from the Kit of Factor-Referenced Cognitive Tests (Ekstrom, French, Harman, & Derman, 1976) with experimental dynamic tests for the remaining three factors.

The study cohort (n=15) consisted of university students and comprised of 13 male students and 2 female students. All participants were studying in STEM disciplines. Each participant was administered the tests individually in a randomized sequence to avoid order bias. Each of the tests is described in Table 1 below.

Table 1. Description of tests used in this study

Factor	Test	Method
Perceptual Alternations - Static Code: PA_S	Necker Cube (e.g. Ishizu & Zeki, 2014)	Participants observe the Necker cube stimulus for a duration of 60 seconds, noting each time their perception varies from one percept to the other. The stimulus covered approximately 8° x 8° of the participants' visual field.
Perceptual Alternations - Dynamic Code: PA_D	Thurstones Windmill (Thurstone, 1944)	Participants observe the Thurstones Windmill stimulus for a duration of 60 seconds, noting each time their perception varies from one percept to the other. The stimulus covered approximately 8° x 8° of the participants' visual field.
Visual Memory - Static Code: VM_S	Shape Memory Test (Ekstrom et al., 1976)	This test contains two parts culminating in a total of 32 items. For each part participants are given 4 minutes to examine an array of abstract visual figures. This is followed by a presentation of 16 figures which participants have 4 minutes to report as being in or not in the previously presented array. Every shape correctly identified is scored as 1.
Visual Memory - Dynamic Code: VM_D	Path Memory Test (Experimental design)	Moving paths were used based on their use by (Pellegrino et al., 1987). The test contains 30 items which consist of a path created by a dot moving across the screen. Each path is viewed 5 times to allow for it to be encoded into memory. Following this, participants have to correctly identify a section of the path based out of 4 potential answers.
Perceptual Speed - Static Code: PS_S	Finding A's Test (Ekstrom et al., 1976)	This test contains two parts culminating in a total of 1640 items. For each part participants are presented with 20 columns of 41 words each. They then have 2 minutes to mark all the words containing the letter 'a'. Every correctly identified word is scored as 1.
Perceptual Speed - Dynamic Code: PS_D	Dynamic Clocks Test (Experimental design)	This test contains 50 items where the participant is presented with an array of clocks with moving hands. For the first 10 items, 2 clocks are shown and the slower clock must be identified. For the remaining 40 items, 3-6 clocks are presented where one is different to the others. The different clock has to be identified.
Spatial Scanning - Static Code: SS_S	Maze Tracing Speed Test (Ekstrom et al., 1976)	This test contains two parts culminating in a total of 48 items. For each part participants are presented with 24 adjoining mazes. They then have 3 minutes to identify the correct path through each maze. Every maze fully navigated is scored as 1.
Spatial Scanning - Dynamic Code: SS_D	Dynamic Mazes Test (Experimental design)	This test contains 30 items containing mazes rotating in a clockwise direction. Participants are instructed to start at the center of the maze and identify the correct exit point on the perimeter. Each item gets systematically more difficult through an increase in the size of the maze and the number of exits.

Findings

As this study presents an initial investigation into dichotomous spatial factors, the analysis first sought to examine the reliability of the experimental tests and where necessary to determine an appropriate approach to increasing their reliability. The results of this analysis are presented in Table 2. The intent of the analysis was to determine appropriate revisions which would aid in achieving a Cronbach's Alpha of .800 (Kline, 2000). While this was achievable for dynamic visual memory and perceptual speed, the nature of the dynamic spatial scanning test meant that only a negligible amount of items were answered incorrectly. The lack of variability prevented modifications to increase the Alpha value beyond .664.

Table 2. Reliability analysis of experimental tests

Test	Initial Alpha Value	No. of Items Removed	Final Alpha Value	Final No. of Items
VM_D	0.628	14	.802	16
PS_D	0.630	8	.804	42
SS_D	0.605	1	.664	29

Subsequent to examining the reliability of the tests, correlations between all measures were examined. Initially performance scores included all test items (Table 3) however it was also examined excluding the items suggested for removal in the reliability analysis (Table 4) as it was envisioned that this may provide further insight.

Four statistically significant correlations were observable when all test items were included. The static versions of perceptual speed and spatial scanning showed a moderate correlation (r = .647, $p < 0.01$) with a moderate correlation also observable in their dynamic alternatives (r = .566, $p < 0.05$). This suggests there may be a difference between static and dynamic cognitive speed with the lack of a statistically significant correlation between the static and dynamic alternatives for each suggesting dissociable cognitive abilities. No correlation was seen between the static and dynamic visual memory tests either which also suggests separate abilities. Interestingly, a moderate negative correlation (r = -.594, $p < 0.05$) is seen between dynamic visual memory and dynamic spatial scanning. Finally, a statistically significant correlation is seen between the dynamic and static perceptual alternations stimuli (r = -.622, $p < 0.05$) suggesting this is a single perceptual ability. The only major statistically significant difference seen with the test items removed is that the significant correlation between dynamic perceptual speed and spatial scanning is no longer observable.

Table 3. Correlation matrix inclusive of all test items

		VM_S	VM_D	PS_S	PS_D	SS_S	SS_D	PA_S	PA_D
VM_S	Pearson's *r*	–							
	Sig. (2-tailed)								
VM_D	Pearson's *r*	.087	–						
	Sig. (2-tailed)	.758							
PS_S	Pearson's *r*	-.040	.290	–					
	Sig. (2-tailed)	.886	.295						
PS_D	Pearson's *r*	-.107	-.212	.125	–				
	Sig. (2-tailed)	.704	.447	.658					
SS_S	Pearson's *r*	-.138	.420	.647**	.251	–			
	Sig. (2-tailed)	.625	.119	.009	.367				
SS_D	Pearson's *r*	-.135	-.594*	-.276	.566*	-.392	–		
	Sig. (2-tailed)	.632	.020	.320	.028	.148			
PA_S	Pearson's *r*	-.105	.210	.049	.318	.363	.090	–	
	Sig. (2-tailed)	.709	.452	.863	.247	.184	.749		
PA_D	Pearson's *r*	-.105	.098	-.264	-.177	-.160	.109	.622*	–
	Sig. (2-tailed)	.710	.728	.342	.527	.570	.699	.013	

**. Correlation is significant at the 0.01 level (2-tailed). *. Correlation is significant at the 0.05 level (2-tailed).

Table 4. Correlation matrix excluding items removed in the reliability analysis

		VM_S	VM_D	PS_S	PS_D	SS_S	SS_D	PA_S	PA_D
VM_S	Pearson's *r*	–							
	Sig. (2-tailed)								
VM_D	Pearson's *r*	.056	–						
	Sig. (2-tailed)	.842							
PS_S	Pearson's *r*	-.040	.364	–					
	Sig. (2-tailed)	.886	.182						
PS_D	Pearson's *r*	-.134	-.086	.139	–				
	Sig. (2-tailed)	.634	.762	.622					
SS_S	Pearson's *r*	-.138	.413	.647**	.198	–			
	Sig. (2-tailed)	.625	.126	.009	.479				
SS_D	Pearson's *r*	-.135	-.534*	-.276	.463	-.392	–		
	Sig. (2-tailed)	.632	.040	.320	.092	.148			
PA_S	Pearson's *r*	-.105	.175	.049	.153	.363	.090	–	
	Sig. (2-tailed)	.709	.533	.863	.585	.184	.749		
PA_D	Pearson's *r*	-.105	.079	-.264	-.133	-.160	.109	.622*	–
	Sig. (2-tailed)	.710	.780	.342	.637	.570	.699	.013	

**. Correlation is significant at the 0.01 level (2-tailed). *. Correlation is significant at the 0.05 level (2-tailed).

Conclusion

The results of this study have generated substantial insight for the progression of this investigation. While a similar study with a larger cohort is needed to verify the findings of this study and a factor analytic approach warranted to determine test validity, refinements can be made to the experimental tests based on these results however the nature of items to exclude must first be examined. The correlational analysis presents some interesting ideas about the dichotomous nature of spatial cognition. It appears that despite the biological differences in static and dynamic visual perception, alternating ones perception may be a singular ability regardless of the nature of the stimulus. In relation to cognitive speed, a broad factor may emerge which differentiates static and dynamic speed which may reveal a new primary mental ability or second-order factor. Finally, it is interesting to see the negative correlation between dynamic visual memory and dynamic spatial scanning. Intuitively, working memory would appear to play a role in spatial scanning as participants may need to remember the path taken if they examine an incorrect route but perhaps the introduction of a rotating environment resulted in a strategy where this was not ecologically rationale. Further exploration into the participants' strategies is warranted to explore this.

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