The Influence of Spatial Ability on the Use of Dynamic, Interactive Animation in a Spatial Problem-Solving Task

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Abstract

This protocol study investigated the differences in problem-solving strategies used by participants with low- and high-spatial ability on a spatial visualization task. The task required participants to draw the cross section of an imaginary 3D computer object. Participants had unrestricted access to two dynamic animations of the stimulus object during the task. Three sources of data were used to analyze performance: 1) frequency of animation use; 2) coded verbal reports; and 3) accuracy on the drawing task. Preliminary analyses suggest that high spatial participants interacted with the animations more frequently did low-spatial participants. High spatial participants also mentioned a greater variety and number of physical and spatial features of the stimulus object than low spatial participants. Finally, high spatial participants drew more accurate representations of cross sections than low-spatial participants.

Introduction

Cognitive psychology research suggests that individual differences among learners in the use of interactive visualizations can influence the amount of learning that occurs (Lowe, in press). Spatial ability is one dimension of individual difference that can influence a learner's ability to extract information from dynamic, interactive animations. In three previous experiments, the author demonstrated that spatial ability and the frequency with which participants interacted with an animated computer model made significant contributions to performance on a spatial visualization task (Cohen *et al.*, 2004). Furthermore, there was anecdotal evidence that high spatial participants used more effective strategies than low spatial participants to extract information from the dynamic, interactive animations. The purpose of this protocol study was to investigate the strategies used by high- and low- spatial participants to perform a spatial problem-solving task in which they had unrestricted access to interactive computer visualizations. The performance task used in this study was identical that used in the author's previous experiments. A possible application of this research is develop training to help individuals with low spatial skills learn effective strategies for interacting with dynamic digital animations.

Method

Participants

Six graduate students (3 high- and 3 low-spatial ability) were recruited to participate in this study. The participants were drawn from two experiments that had slightly different instructions. All participants were screened for spatial ability based on the Guay-Lippa Visualization of Viewpoints (Guay, R. & Mc Daniels, E., 1976, as modified by Lippa, *et al.*, 2002) and the Vandenberg Mental Rotation Test (Vandenberg & Kuse, 1978).

Materials

The participants completed 12 paper-and-pencil trials in which they drew the cross section of an imaginary object. The stimulus figure was egg-shaped, with a transparent exterior that revealed an internal network of duct-like structures (Figure 1). Pictorial depth cues, such as highlights, shadows, and visual occlusion suggested spatial depth in the figure. A fictitious figure was used in order to avoid any confound introduced by participants' recognition of a familiar object

During all trials, participants had unrestricted access to two interactive animations of the egg-shaped stimulus object. In one animation the stimulus object could rotate 360^0 around its vertical axis, while the

second showed a 360^0 rotation around the object's horizontal axis. Each animation had a slider bar that allowed the participant to pause the rotation at a particular view of the stimulus figure. The slider bar also allowed participants to advance or reverse the rotation at a self-controlled speed.

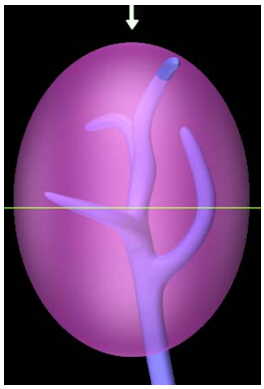

Figure 1. The stimulus object used in all trials. The horizontal line indicates the imagined cutting plane for Slice 13.

Procedure

Participants were tested individually. The experimenter explained the term "cross section" and the requirements of the task. Three participants saw an image of stimulus figure adjacent to an image of the cross section that would result from a cut at an indicated plane. These participants also saw a small clay model that was sliced to reveal a cross-sectional plane. The remaining participants read instructions that included an illustration of a semi-transparent apple and the cross section that would result when the apple was viewed from an indicated perspective and sliced at a specified cutting plane. These instructions further specified the required elements of a drawing of a cross section: the outer contour of the cross section and the contours of the internal structures, (the sliced ducts.)

Further instructions printed on the trials for all participants asked them to imagine viewing the egg-shaped stimulus figure from the perspective of an indicated arrow, to imagine the figure being sliced at an indicated line, and to draw the resulting cross section.

Participants were asked to 'think aloud' as they completed the drawings, and were videotaped as they performed the performance measures. There was no time limit for experiment.

Animation Coding. Videotapes of each participant's performance on the trials were reviewed and coded for frequency of animation use. A single instance of animation use was defined as the participant's manipulation of either the horizontal or vertical animation.

Verbal Protocol Coding. The verbal report of each participant's 'think-aloud' protocol was transcribed and coded for the frequency with which they mentioned physical and spatial features of the stimulus figure. Table 1 lists some of the features that were coded in the verbal protocols.

	2D	3D	Imagined
Features of the stimulus object			
number of cut ducts			
outer contour of slice			
duct shape			
duct size			
angles between ducts			
global duct position			
arrow			
Cutting plane			
location			
orientation			
Viewing perspective			
location			
orientation			

Table 1. Coded features of the verbal protocols.

Coding of Drawings. Participants' drawings were coded for accuracy based on four elements of their drawings: 1) the number of ducts represented; 2) the outer contour of the slice; 3) the angular relationships among ducts; and 4) the global location of the ducts on the drawing of the cross section.

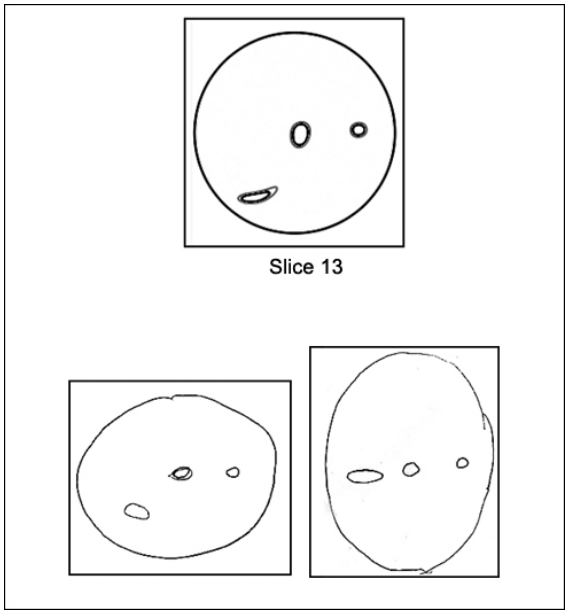

Figure 2: Accurate representation (above) and two participants' drawings (below) of Slice 13.

Results

Participant Interactivity

High spatial participants used the animation more frequently than the low spatial participants (Figure 3). One low spatial participant expressed difficulty mapping locations from the two-dimensional stimulus trials onto the animations. At various times during the trials, she turned the binder holding the two-dimensional trials upside down, and lifted them above her head and viewed them from below. This participant said:

> The computer, when it turns, I have no…I feel like I have lost my bearings when I go with it…but with the book (*the binder of stimulus problems*) at least I have some...grounding.

High spatial participants, on the other hand, often developed efficient strategies for interacting with the animations. One high spatial participant demonstrated a strategy for determining the degree of stimulus object rotation that resulted when the slider bar was advanced incrementally along its length:

> ….I guess, if that's a full rotation *(moving the slider bar from one end to the other*), then I can use it to go half way around…and that's about a quarter. I think this is a good technique we've got here. Since it's a full rotation from one side to another, a half rotation should be 180 degrees, and then (*as he advanced the slider bar incrementally*) 90, 180, 270, 360.

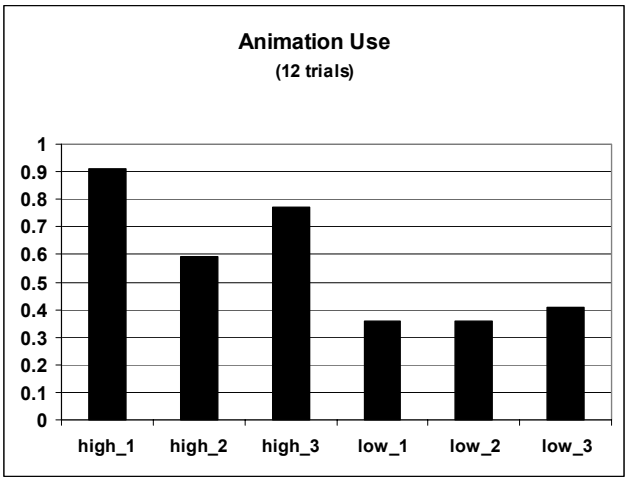

Figure 3. Proportion of possible instances in which participants used interactive animation for 12 trials.

Verbal Report

High spatial participants mentioned more physical and spatial features of the stimulus figure than did low spatial participants (Figure 4). The greatest difference between high- and low-spatial participants in verbal report was seen in the mention of the cutting plane; high spatial participants mentioned the cutting plane almost twice as often as low spatial participants. Of further interest is the trend for both high- and low- spatial participants to mention view orientations less frequently than they did features of the stimulus object and the cutting plane.

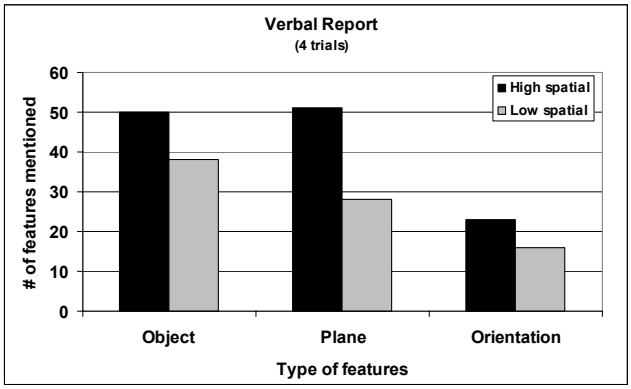

Figure 4. Physical and spatial features mentioned by high- and low-spatial participants.

Cross-sectional drawing accuracy

Figure 5 compares the accuracy of drawings produced by the high- and low-spatial participants. The accuracy score is the mean of three variables: outer contour of the slice, angular relationships among ducts and global location of ducts (see *Coding of Drawings* in the *Procedure* section).

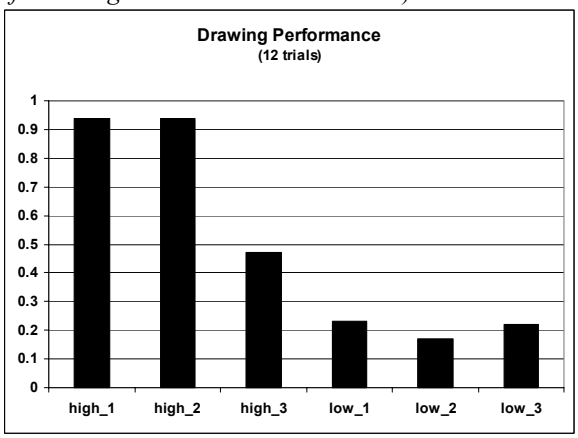

Figure 5. Performance as measured by an aggregate performance variable.

Discussion

Results of this study indicate that: 1) high spatial participants used the interactive animation more frequently than low spatial participants; 2) high spatial participants mentioned more physical and spatial features of the stimulus object than low spatial participants; and 3) high spatial participants drew more accurate representations of cross sections than low spatial participants.

The fact that high spatials mentioned a greater variety and number of physical and spatial features may indicate that they are more aware of the spatial relationships required visualize cross sections of a three-dimensional object. There was also a qualitative difference in the type of object features mentioned by high- and low- spatial participants. Low spatial participants tended to mention surface features of the object, such as color and shading, while high spatial participants more often mentioned shapes and angular intersections within the object. Although shading is an important two-dimensional depth cue, more revealing three-dimensional depth cues were available to participants who rotated either or both of the animations.

Of interest is the fact that both high and low spatial individuals mentioned view orientations less frequently than the other two classes of feature variables (object features and cutting plane features.) Mental representations of at least three different view orientations were required in order to imagine, and draw, the correct representation of a given cross section. Only two of these three view orientations were visible at any given time: the two-dimensional view of the object as seen in the paper-and-pencil problem, and the view of each animation, which would change only upon the participant's interaction. The third view orientation, the representation of the "correct answer," must be imagined by the participant, or inferred from spatial information provided in the interactive animations. Perhaps this is the hardest element of the task for participants across abilities since it requires the participant to engage working memory and problem-solving resources.

Visualizing the unseen cross section of an unfamiliar object involves mental transformations of given views, or, in the case of this study, interactivity with external visualizations. The initial coding of the verbal protocols suggests that low spatial participants were less aware of key spatial features and

relationships than were high spatial participants. If the low spatial participants were unaware of the importance of particular spatial features and views, they presumably would not be motivated to interact with the animation in order to get more information. This is a possible explanation for their lower frequency of interactivity with the animations, compared to the high-spatial participants. Furthermore, the low-spatial subjects' inability to use the animation effectively might have resulted from their difficulty mapping the two-dimensional features and relationships seen in the stimulus drawing onto the rotating animations. More detailed coding of the verbal protocols, and the addition of behavioral coding from the videotapes, will add to this preliminary model of interactivity in a spatial problem-solving task.

References

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