Micro to Macro… Investigating the complex cognitive processes in forming and externalizing visual imagery

Diarmaid Lane
Department of Design and Manufacturing Technology
University of Limerick

Dónal Carty
Department of Design and Manufacturing Technology
University of Limerick

Abstract

Externalizing visual imagery through freehand sketching is a highly complex cognitive skill. It requires the synthesis of short term visual memory, spatial skills and precise psychomotor skills. The research described in this paper examined the relationship between spatial ability, blind haptic manipulation and freehand sketching strategies across a multi-disciplinary group of undergraduate participants. A specially designed haptic manipulation / sketching test was developed in order to examine the strategies used by participants while physically examining and sketching a range of artifacts. The findings suggest that participants with high PSVT:R scores utilized more efficient blind manipulation strategies, appeared more confident to sketch pictorially and generated higher levels of detail in their completed sketches. Although the sample size was relatively small we believe that the nature of the applied test and subsequent results will be of particular interest to engineering graphics educators who wish to better understand the cognitive nuances of different spatial ability groupings.

Introduction

Research in spatial visualization skills is traditionally associated with the internal formation, manipulation and synthesis of perceived visual imagery (Sorby, 1999, Reiner, 2008). Freehand sketching has been found to be beneficial in developing spatial skills (Sorby, 2003) and special sketching activities have been successfully integrated into spatial skill development programs (Lane et. al., 2012). Other research concerned with local touch found that the development of haptic skills should be integrated into programs of instruction (Study, 2003) as haptic information contributes to the micro details of visualization while the macro details are synthesized by the human visual system (Reiner, 2008).

This paper presents the results of a study that investigated the relationship between scores in a spatial skills test, blind haptic manipulations of geometries and the subsequent externalization of these through freehand sketching. The following were the primary objectives of the research study:

1. To examine the relationship between attainment in spatial visualization tests and the ability to formulate visual mental images through blind haptic manipulation

2. To examine the relationship between strategies used in blind haptic manipulations and subsequent externalizations through freehand sketching
3. To analyze the nature of blind manipulation strategies used by participants in developing visual mental images
4. To examine the relationship between cognitive-load, working memory and object familiarity during the experimental tasks
5. To analyze the sketching approaches utilized across a diverse range of spatial visualization test scores and the quality of sketches generated

Method

Participants

A total of eight participants volunteered to take part in this investigative study. Six participants were final year undergraduate students in an initial technology teacher education program at the University of Limerick, while two participants were from non-graphics courses. The Purdue Spatial Visualization Test Visualization of Rotations (PSVT-VOR) was administered to all participants and the results were subsequently analyzed. The participants were then categorized according to their scores. Up to this point in their studies, the six participants on the teacher education program had completed five semesters of study in the area of graphics with specific focus on plane geometry, descriptive geometry and communication of design. The remaining two participants were undertaking completely unrelated courses and had received no previous instruction in technical graphics.

Haptic manipulation / sketching test

A specially designed haptic manipulation / sketching test was administered in order to record and analyze a number of behaviors including; kinesthetic (proprioceptive) movement, manipulation time, number of manipulation episodes and the nature of sketching strategies. In order to capture this complex information a number of discrete webcams were positioned internally and externally to the unit shown in Figure 1. The internal camera recorded the kinesthetic movements while the external camera recorded the sketching behavior.

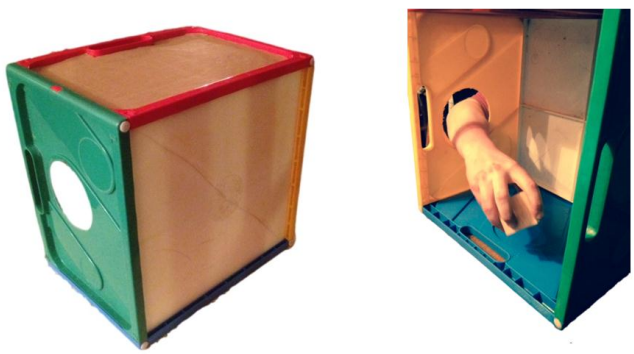


Figure 1 – Set up for the blind manipulations

The dual recording of the kinesthetic movement in the haptic manipulations and the sketching behaviors enabled the researcher to analyze the relationship between both throughout the task (Figure 2).

Figure 2 – Internal and external webcam recordings

Various test objects were used in this investigation and were divided into two categories:

1. *Unfamiliar objects*
2. *Familiar objects*

The unfamiliar objects utilized were simple compounds of regular solids such as cones, cylinders, cubes, rectangular prisms and octagonal based prisms. Eight objects were arranged in various configurations (Figure 3) and ranged in complexity (determined by the number of vertices on each).

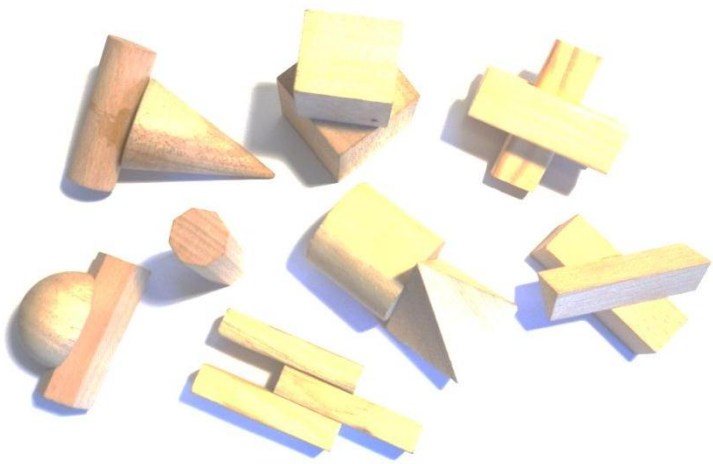


Figure 3 – Unfamiliar objects

The familiar test objects selected in the haptic visualization investigation are shown in Figure 4. The rationale for the selection and use of these objects was to determine if previous object familiarity affects kinesthetic movement strategies and the quality of sketches generated. There was no time limit implemented for either task.

Figure 4 – Familiar Objects

Findings

The data collected during the study were highly complex and rich in nature. The participants of this investigative research had a diverse range of scores in the PSVT:R test (Figure 5). For the purpose of this paper we decided to present the findings for two participants in detail. The participants were selected from either end of the PSVT:R scoring spectrum. Participant C, a 21 year old male, had a PSVT:R score of 29. Participant F, a 21 year old female, had a PSVT:R score of 7. It is not the intent of the authors to differentiate between behaviors of males and females. The sole purpose was to compare and contrast the behaviors of participants who are categorized by PSVT:R performance.

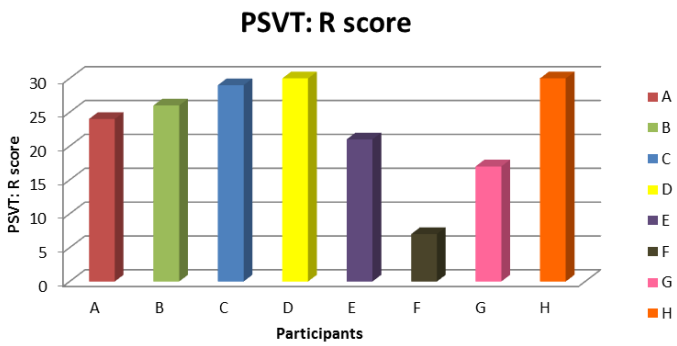


Figure 5 – Participant PSVT:R scores

An analysis of Participant C

Participant C completed the task six times. On each occasion the investigator selected the target object. Three familiar objects and three unfamiliar objects were examined by the participant. The total time taken for the each task and the total time haptically manipulating each object is presented in Figure 6.

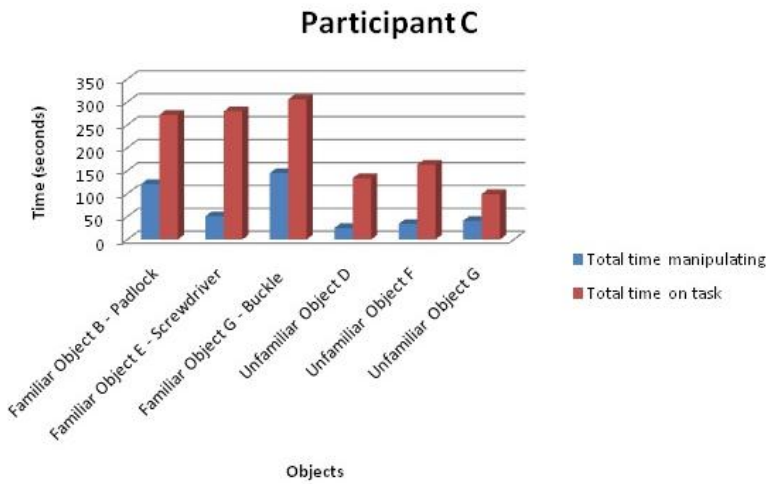
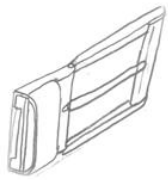
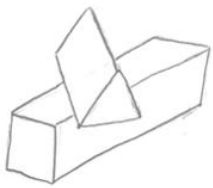
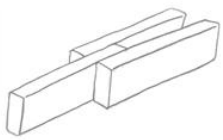
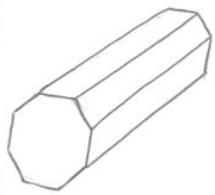


Figure 6 – Participant C performance

The resultant sketches generated by Participant C for each task are illustrated in Table 1. It is evident that the participant effectively communicated each object with sufficient detail. The relationship between the geometries and communicated proportions in each sketch are very similar to the physical object. It is interesting to note that each sketch was communicated in isometric with the primary orientation of the sketch rotated at approximately 30°. Basing the complexity of each object on the number of vertices, it is notable that the most time spent on any one task was for Familiar Object E (Figure 6). Sole examination of the generated sketches does not reveal any significant difference between the quality of sketches generated for familiar and unfamiliar objects.

Table 1 - Participant C sketching performance

	Familiar Object B	Familiar Object E	Familiar Object G
Physical Object			
Sketch			
	Unfamiliar Object D	**Unfamiliar Object F**	**Unfamiliar Object G**
Physical Object			
Sketch			

Key observations of recorded videos for Participant C

The following are some key observations recorded by the researcher during the analysis of recorded videos for Participant C.

- The participant required further manipulations soon after initial manipulation. This highlights the concept of cognitive load and its effect on working memory capacity.
- They paid very close attention to detail as they extensively examined complex features.
- Smooth, fluent sketching techniques were evident.
- The sketches were approached in a step by step manner as the participant clearly concentrated on the various geometries of each object.
- Initially sketched a light outline of the objects.
- Utilised one hand only for manipulations while attempting to depict complex features of objects with opposite hand.
- The participant sketched the object in the orientation it was placed after manipulation.
- No conclusive observations were made in terms of object familiarity and the quality of sketches generated.

An analysis of Participant F

Participant F completed the task six times. On each occasion the investigator selected an object. Three familiar objects and three unfamiliar objects were examined by the participant. The total time taken for each task and the total time haptically manipulating each object was examined Figure 7.

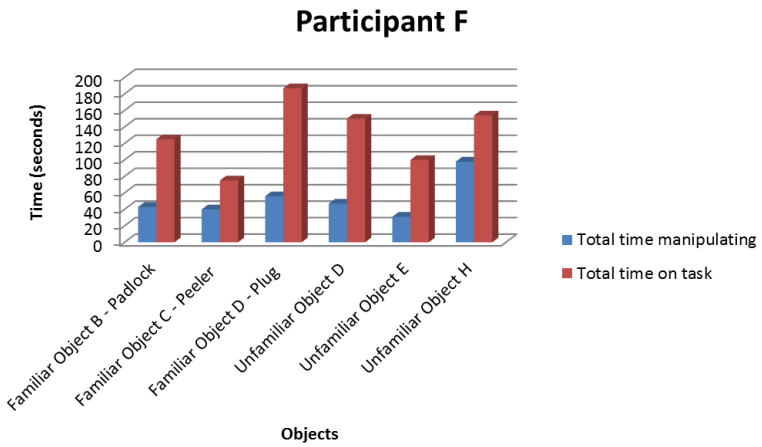


Figure 7 – Participant F overall performance

The resultant sketches generated by Participant F for each task are illustrated in Table 2. Initial examination of the sketches suggests a significantly poorer quality in contrast to those generated by Participant C. Although the sketches for each of the familiar objects are identifiable, the relationships between the communicated geometries are not accurate. This is particularly noticeable in Familiar Object B and Familiar Object D, where the participant struggled to pictorially represent the objects. While Participant C tended to sketch the objects in an isometric orientation, Participant F seemed to struggle with this. Another notable observation is that Participant F had difficulty in effectively communicating the curved geometries in Unfamiliar Object E and Unfamiliar Object H.

Table 2 – Participant F sketching performance

	Familiar Object B	Familiar Object C	Familiar Object D
Physical Object			
Sketch			
	Unfamiliar Object D	**Unfamiliar Object E**	**Unfamiliar Object H**
Physical Object			
Sketch			

Key observations of recorded videos for Participant F

- A high number of manipulations occurred in very short time periods. This indicates that the participant possibly had difficulty in effectively formulating clear visual mental images.
- The participant evidenced a very passive style of manipulation. They tended to rest / place their hands on the object and did not manipulate the objects in any great detail.
- Object familiarity appeared to be a problem as the participant noticeably encountered difficulty with the unfamiliar objects.
- The participant appeared to be very hesitant at times while sketching. Perhaps this is an indication of poor sketching ability or poor formulation of visual mental images.
- Appeared to focus on the outside boundaries of objects.

Conclusions

The purpose of this paper was to describe a method of capturing the cognitive and psychomotor behavior exhibited during tasks that involve blind haptic manipulation of objects and the subsequent sketching of these. The method and resultant findings should be of interest to educators, researchers and students of engineering design graphics. In order to better comprehend the micro and macro

complexity of spatial visualization skills and the role of freehand sketching in communicating visual mental imagery we believe that this type of research study is of particular importance. The following is a brief summary of key observations and some associated pertinent questions; we hope that these will stimulate some thought and discussion among the engineering design graphics audience:

1. Participants with high PSVT:R scores appear to utilise more efficient manipulation strategies than those with low PSVT:R scores. These manipulation strategies include contour following to detect shape, grasping to identify volume, and lateral motion to determine texture. The participant with the lowest PSVT demonstrated a passive style of manipulation where the complex features of objects was not examined in depth. **Question:** Should we teach students how to effectively manipulate physical objects in order to obtain effective haptic feedback?
2. The participants with low levels of spatial ability appeared hesitant in their sketching with very modest attention to detail. They tended to focus on the objects as a whole rather than dissecting them into basic features. In contrast, those with high spatial visualisation ability demonstrated fluid sketching techniques while demonstrating greater attention to detail. This correlates with findings in other research studies that examine sketching expertise (Lane, 2011, Middleton, 2008). **Question:** Is there enough focus across engineering education in developing students' freehand sketching skills? Has the digital age smothered out paper and pencil externalizations?
3. Previous examination of an object in one modality aids the identification of that object in the haptic modality. It is considered that object familiarity provides an almost immediate mental image of the general shape but doesn't necessarily alleviate the amount of manipulation required due to the need to examine the intricate details of object. **Question:** In developing classroom activities, should we integrate more images of familiar objects that will be of interest to students? What effect could everyday / familiar imagery have if incorporated into spatial skill tests? This research question is currently being investigated by Ernst et al. (2014).

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