Assessing Information Presentation Preferences with Eye Movements

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Abstract. This study investigates the relationship between participants' self-reported high verbal or high visual information preferences and their performance and eye movements during analytical reasoning problems. Twelve participants, six male and six female, were selected as being more visual than verbal or more verbal than visual in approach, based on the results of a questionnaire administered to 140 college students. Selected participants were tested for individual differences in spatial ability and working memory capacity. They completed a repeated measures experiment while their eye movements were tracked to examine any correlation with their stated preference for verbal or visual information presentation. Performance on analytical reasoning problems with and without an optional diagram is compared between groups and within-subjects. Due to the small number of participants, between-group differences, although indicated, were mostly statistically insignificant. Within-subject analysis is still being completed, but trends in diagram usage are examined.

Keywords: information presentation, eye tracking, analytical reasoning, problem representation.

1 Introduction

Various studies have found signs of cognitive style or learning preferences in some individuals for either a textual or text plus graphic representation of information[1, 2]. This is often referred to as a visual-verbal preference for information presentation and is dependent on the task and situation even for a given individual. Several tests have been used to measure any tendency for one or the other, but the construct is thought to be related to three factors: one's spatial visualization ability, visual-verbal learning preference and visual-verbal cognitive style [3]. The first factor refers to an ability one has developed to mentally manipulate and transform shapes. The second factor refers to one's preference for educational material to be presented textually or with graphics as well. The third factor refers to the tendency or belief that one's thoughts tend to be more visual or more verbal in nature, or that one has developed a habit of a visual or verbal approach to problem solving. At the same time, there has been conflicting usage of terminology, measurement, and significance of the construct.

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Studies have shown self-constructed representations for analytical reasoning falling into either diagrammatic or verbal categories [4, 5], and that some people may rely on mental imagery more to solve mechanical reasoning problems than others [6]. It is of interest in this study whether these groupings would correlate with other verbal-visual factors. Although correlating individual differences with behavior is difficult, it is necessary to try to determine whether visual-verbal factors influence problem representation preferences and whether visual strategy can be used to predict visual-verbal factors to be augmented.

Although the existence and possibility of visual imagery is a controversial topic in psychology [7-9], the current study is concerned more with the match between one's perception of oneself as a visualizer or verbalizer and one's actual perceptual practice than whether one is actually able to encode thoughts as images. There is also debate whether individual differences determine a significant level of variation between individuals or are reliable enough factors to be worthy of information system design research, because they can change with the task or context, even for a given individual [10].

However, as user modeling and augmentation improves, a better understanding of the verbal-visual construct, and what it means in terms of interface design and problem representation is warranted. There is indication that differences are very task dependent and studies have had conflicting results as to the importance of cognitive style because people are able to adapt to the information format as needed. Yet, there seems to have been little effort to find physiological evidence of visual-verbal individual differences that might provide behavioral support for any design implications. The work of Riding and Peterson are an exception to this [11, 12].The current study is an attempt to help clarify the perceptual aspects of the visual-verbal construct, if only in the narrow realm of solving relatively simple and determinate analytical reasoning problems on a computer screen.

2 Previous Studies

In this section a brief overview of some relevant eye tracking and visual representation research is provided.

2.1 Eye Tracking Studies

Eye tracking research has been instrumental in our understanding of visual perception processes. Although the technology for tracking eye movements is far from perfect, it is one physical measure that can help us understand what people look at in order to understand their environments. It is physically possible to track what a person is viewing within one degree of their pupil position, which represents the area that their foveal receptors can accurately perceive without eye movements. Peripheral vision outside the fovea is not usually clear enough for viewing details but is useful for drawing attention to a target. So, eye tracking allows us to know what a person is looking at within one degree of the eye position, and current accuracy is usually between one and two degrees where one degree is .4 inches or 40 pixels on a display placed 24 inches from the viewer [13]. The abrupt eye movements between one target and another are called saccades. Saccades can span from 1 to 40 degrees and are sudden movements during which the direction of the movement cannot be changed once started. They occur 100-300 milliseconds (1 ms. = 1/1000 sec.) after the target appears in peripheral vision. A saccade is usually followed by a fixation lasting between 200-600 milliseconds. During a fixation, small movements of less than a degree may occur to focus the area of interest on the fovea. Gazes are usually defined as collections of fixations and small saccades within an object or section of the viewing area [14]. The pupil size can also indicate things about the viewer and level of cognitive activity. Fixation duration is a measure of difficulty of information extraction and interpretation; while the number of fixations in a region indicates level of interest [15].

The literature on eye tracking in HCI is divided into three main groups: research to understand what the user is looking at on the screen, using eye tracking for interface evaluation, and most recently as an input device for attentive interfaces. This research falls into the first category, but the results could be important for the other two categories in the future. One general finding has been that eye movements in scene perception and search depend on the task. The author's previous studies have shown that it is possible to determine task and complexity from eye fixation data and train a neural network to recognize the task at very high levels of accuracy [16, 17].

Cognitive style as measured by the Meyers-Briggs Type Indicator's sensing/intuitive dimension was found to determine scanning patterns for both textual and graphic programming tasks, independent of the person's experience and comprehension level [18]. The sensing type has a preference for information "sensed" in the environment from concrete experience. The intuitive type prefers abstract possibilities, meanings and relationships. It is unclear how and if these types relate to a person's visual or verbal preferences, but the study shows a linkage between cognitive style and perceptual processing.

Much of the eye tracking research on diagrams for problem solving has focused on diagrams of mechanical devices. Of particular interest in these studies is a finding that subjects have a tendency to decompose the diagram into components that are believed to be mentally animated to help them determine causal relationships between different components [19]. Eye tracking showed that the relevant components are viewed during mental animation, and that working memory capacity limits constrain the ability to imagine component behavior. This is another indication of how working memory is important in problem solving.

Studies have shown that some people move their eyes in relation to their internal imagery even when looking at a blank screen and visualizing from memory after the image is removed. Eye movements matching the location of previously shown key components on the blank area of the screen were observed for 42% of participants in a problem solving task where the first problem was illustrated with a diagram and the second was not. It was hypothesized that those with eye movements in the blank area of the screen for the second problem were visualizing the diagram to solve the problem, even though the diagram was no longer present. The other 58% focused almost exclusively on the text of the question and problem on the second problem. This study did not test subjects for visual-verbal cognitive style or learning preferences, or memory capacity so it is impossible to know if it correlated with the imaging and non-imaging subjects [6].

2.2 Visual Representation

External representations facilitate problem solving by computational offloading among other functions [20-22]. Graphic representations accompanying text can improve retention of main facts by making concepts less abstract and emphasizing main points, e.g., [20, 21, 23-26]. Graphic representations are most useful in determinate problems because of increased notation and symbols for indeterminate problems [27]. Pictures and diagrams have been used to facilitate communication and understanding since the first cave drawings. Narayanan broadly defines diagrammatic communication as “an overarching theme that encompasses not only diagrammatic representation but also diagrammatic reasoning and diagrammatic interaction between humans and computers” in his review of taxonomy of diagrammatic communication [28]. Various aspects of diagrammatic communication are increasingly relevant with increasing information overload and the pressing need to communicate essential relationships and information from vast and complicated problems that we face as groups and individuals.

The best sources of information on how best to communicate information visually are found in Edward Tufte’s aesthetically appealing and detailed work [29-31]. Although based more on his experience and aesthetic sense than empirical evidence, Tufte’s main principal can be summarized that additional ink should always add meaning or it should not be used. In this study we are looking for differences in perceptual strategies in a problem-solving task and on the use of diagrams for communicating problems. Unfortunately, the literature is very sparse in this area and most deals with studies comparing different types of diagrams such as tables and bar charts.

Visual and verbal cognitive styles and learning preferences represent habits and approaches to thought and information processing [15, 32]. Visualizers prefer literal encoding (seeing, feeling physical features when relating information to prior knowledge), and use mental pictures when thinking. Verbalizers prefer linguistic encoding (reading how to do something), and use inner speech when thinking [15].

In a recent study on the effectiveness of visual interactive modeling on group decision making found that visualization improved efficiency and satisfaction, however, unexpectedly did not improve the quality of the decision made compared to a group not using the visualization technology [33]. Studies such as these may be explained if the decision maker’s visual and verbal style is measured as well.

Another recent study on the effect of photos on newspaper processing found that verbalizers had better recall of both pictures and stories than visualizers, and that visualizers did not show more interest in stories with photos, and the best recall was by the high verbal/low visual type [34]. These results add to the evidence that visual-verbal style does affect learning, but leads one to the conclusion that reading a newspaper is a verbal task that visualizers may not excel at regardless of the use of photos to enhance interest. It would be interesting to know if diagrams would have had the same lack of enhancement in recall for those testing highly in visual style. The educational psychology literature has more work on the implications of cognitive style and other individual differences on curriculum, but much of the problem solving literature deals with teaching math and science using pictures, diagrams and animations as opposed to preferences for diagrams or text in analytical reasoning [1].

3 Methodology

To better understand the relationship between diagrammatic communication and problem representation in relation to the visual-verbal characteristics and preferences of the viewer, this study looks for eye movement and performance differences as evidence of preference differences in the use of diagrammatic and textual representations of problems. The visual-verbal factors were measured using established visual-verbal learning preferences and imagery questionnaires and psychological tests to measure spatial visualization ability and working memory capacity. Participants were observed and tested through an eye-tracking experiment to see if correlations between visual solution strategy and individual differences relating to verbal-visual preferences are detected and match the stated and expected preferences of the individual.

3.1 Research Design

This research is based on data from a repeated measures experiment where participants perform problem-solving tasks using analytical reasoning with and without ancillary graphic representations of some of the problem information. The performance on the tasks is based on the time to complete the problems and the number of correct answers. The performance with and without a graphic is being compared within subjects. The proportion of fixations and time spent on graphic elements, is compared both within subjects and between subject groups.

As a screening tool, participant pools were asked their preference for verbal or visual descriptions for learning and thinking using a verbal-visual preference questionnaire. The questionnaire is based on an adaptation of Richardson's Verbal-Visual Questionnaire [35], and Mayer's verbal, spatial, and visual-verbal learning style rating tests [3]. Mayer and Massa suggests that individual visual-verbal learning style rating correlates highly with other measures of visual-verbal cognitive style and learning preference [3]. The questionnaire was used to screen approximately 140 participants to find twelve that were measured as more verbal or more visual. This selection was done to accentuate any verbal and visual effect on eye movements.

In the experiment, the selected university students solved analytical reasoning problems to see how they view verbal and diagrammatic representations to solve a problem or accomplish a task. The participants were tested individually. First they were given a short test to measure their working memory span using a number span test and a timed paper folding test from the Kit of Factor Referenced Cognitive Tests [36] to measure their spatial ability. Then each participant performed a computerized experiment while connected to an ASL eye tracker. Their eye movements were tracked 60 times per second while they solved a series of problems using the textual and/or graphic information provided. Two sets of questions asked the participant to solve analytical reasoning problems. One set included an ancillary graphic representation with some of the information from the textual information. The other set of questions included only the textual information, and after finding the solution, they were asked to choose between Venn diagrams, a matrix, a network, and a hierarchy as the basic structure of the previous problem presented textually. Their performance was measured on the accuracy of their answers and the time taken to complete the problems.

Participants were given an opportunity to discuss the tasks and their experience after the experiment. The interaction between performance and type of representation is being analyzed in terms of other individual characteristics provided, such as spatial ability, visual-verbal preference profile, and memory capacity. All problems were designed to be solved while viewing a computer screen without additional notes or calculations, although for increased difficulty some require more working memory capacity than others.

3.2 Participants

Twelve participants were recruited from university students attending classes in language, information science, computer science, and business. A visual-verbal questionnaire was used to screen approximately 140 participants to find six extremely verbal and six extremely visual participants for the full experimental protocol. The participants were familiar with using a computer, mouse, and have some experience solving analytical reasoning problems such as those on standardized tests. The participants' data was grouped by spatial ability, working memory capacity, visual/verbal thinking, and visual/verbal learning preference to be compared for significant differences in performance and use of external representations.

3.3 Treatment

The eye movement data was collected while participants complete a computerized experiment. Section A contained a practice problem followed by five textual problems with graphic representations. Section B had a practice problem followed by five textual problems without graphics. This was followed by a question asking them to select the appropriate diagram for the problem.

The performance on the parallel problems in sections A and B are being compared for accuracy, and time to complete within subject. The performance is then analyzed in correlation to their measured or stated visual/verbal factors between subjects. The proportion of fixations on the graphic support in section A is also being analyzed for patterns relating to their visual/verbal factors.

The experiment takes about 45 minutes with breaks between the sections to allow the participant to relax. The questionnaires and psychological tests were done with paper and pencil and numbered to protect anonymity. Every attempt was made to make the participant feel relaxed and comfortable during the session.

4 Results

The data from this study is still being analyzed. The between group results show a trend for differences between the visual and verbal groups in duration of time spent on the text plus graphic section and the text only section. The differences in the means for the visual and verbal groups are not statistically significant for most variables.

Table 1. The means for the different measures for the visual and verbal groups

	Type	N	Mean	Std. Deviation	Std. Error Mean
Spatial test (max 10)	visual	6	5.7917	2.16458	0.88369
	verbal	6	6.9583	1.56857	0.64037
Memory (max 53)	visual	6	45.50	5.244	2.141
	verbal	6	46.00	5.329	2.176
Sect A w/ diagram correct (5)	visual	6	4.50	0.837	0.342
	verbal	6	4.17	0.983	0.401
Sect B w/o diagram correct (5)	visual	6	3.17	0.408	0.167
	verbal	6	3.83	0.983	0.401
Sect C correct (5)	visual	6	4.00	1.095	0.447
	verbal	6	4.17	1.169	0.477
Total Correct (15)	visual	6	11.67	1.033	0.422
	verbal	6	12.17	1.941	0.792

However, it is interesting to note that despite the lower average spatial visualization score, the visual group scored higher on the problems with diagrams. This is being investigated within subject to see if the trend is based on a particular strategy.

The duration of time spent on each problem is similarly interesting yet there is no clear statistical result in the between group comparisons. There seems to be a trend for the visual participants to spend more time on the diagram, and the verbal participants to spend more time on the text, but this analysis is incomplete. These results will be presented and clarified at the time of the conference.

5 Conclusion

Through this study we hope to gain a better understanding of how and when external representations are effective for analytical problem solving and for whom. The results and analysis should add to our knowledge of representations used in diagrammatic communication as well. It has been shown that illustrations can both distract and enlighten the viewer during learning. The same should be true for diagrammatic communication and it is hoped that eye tracking will lead us to a better understanding of the user of diagrams for representing analytical reasoning problems. If information presentation preferences are relevant to systems design and diagrammatic communication, it should be evident in the eye movements and performance of the participants doing analytical reasoning problems.

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