The Interactions Between Visual Perception, Visual Attention and Graph's Processing

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ABSTRACT

The ability to process information that is presented in graphic format is one of the skills necessary for living in our modern society. The uniqueness of a graph lies in its ability to convey to the reader/viewer a more concise and tangible message than a table of data can convey. This is conditional upon the reader understanding the language that the "graph speaks" (Mor, 1995). Even though the building and processing of graphs are important elements of the curriculum of various branches of knowledge, it is apparent that many students have difficulty in graph processing. These difficulties are found in all age groups, from students in elementary schools through those in universities. It seems that many students have prior knowledge of and approaches to processing graphs which affect the top-down learning skills of graph processing. In addition, it is known that the characteristics of the visual information which is displayed by a graph can have an effect on the ability to process a graph, and thus also the bottom-up processes influence the graph processing.

RESEARCH QUESTIONS

Question 1: What is the effect of cognitive load on graph processing?

Question 2: What is the relationship between individual characteristics and the ability to process a graph correctly?

Question 3: What is the relationship between eye movements during graph reading and higher cognitive processes?

METHODOLOGY

In order to test the ability to process graphs and the influence of bottom-up and top-down processes on graph processing, a number of tests were conducted, that will be discussed below.

The research sample consisted of 40 students. They came for two sessions held two weeks apart in the laboratory. During the first session, the subjects answered a questionnaire about their approach to dealing with graphs and their graph literacy. They then were asked to take two tests of graph processing. One was the GPTI (Graph Processing Type I) and another test, either GPT3 or GPT4. The tests took place while eye tracking was done. The second session had four parts: the taking of the GPT2 without eye tracking, the Navon paradigm, the d2 test, and parts of the Wechsler Adult Intelligence Scale test (matrix, digit-symbol, forward memory, and backward memory [counting backwards]).

The GPT1-4 is a computerized, multiple-choice test that was designed for this research. The test measured the ability of the subject to process information from a line graph. In addition to the eye tracking, the test collected information on behavioral indices, the accuracy of the processing, and the reaction time needed to answer. The questions on the test were divided into seven levels of cognitive load. The cognitive load was created by a combination of three factors: visual load, the type of question, and the prior knowledge of the subject. Additional cognitive load was created by changing the pre-test directions related to the graph processing and by the necessity to answer a question related to the graph. On the GPT1 there was no requirement to answer a question after looking at the graph, and there were no pre-test directions or questions about processing the graph. On the GPT4 there were no pre-test directions or questions about processing the graph; rather a question was posed only after the graph was process. In the GPT2 and GPT3, there were directions/questions before the test. On the GPT2, the question was posed together with the graph; on the GPT3 the question was posed before the graph was presented.

MAIN RESULTS

1. The analysis of the behavioral results indicates that a number of parameters affect the cognitive load associated with the task, and they can influence the strategy and ability to process a graph. The three parameters are: the type of question, the subject's previous knowledge, and the degree to which directions were given or questions were posed before the test (pretest directions). In contrast, the visual load had no effect on the graph processing strategy. Furthermore, it was found that the absence of any pretest directions about the processing created an additional cognitive load, which was reflected in a lengthening of the reaction time and a decrease in the degree of accuracy, mainly with respect to the questions in which the cognitive load was low. But vis-à-vis the questions where the cognitive load was high, the factor that limited the accuracy and the reaction time was not the amount of pretest direction but rather the fact that the graphs were not very routine and prior knowledge was non-existent with respect to their graph processing. That is, there were no prior schematic frameworks that would have shortened the reaction time and the load on the working memory increased. Therefore, greater graph literacy is needed In order to correctly process the information presented on these graphs. As stated above, the visual load had no effect on accuracy or on the reaction time.

The visual load did affect the bottom-up processes and three other factors: the type of question, the prior knowledge, and the degree of pretest direction. They are the top-down factors that affect the reaction. **This is to say that according to the behavioral results, the top-down processes had a great effect on the graph processing strategy.**

2. No connection was found between the d2 test and the graph processing, while a partial connection was found between the Navon paradigm and graph processing. These findings strengthen the conclusion that these are processes which are directed mainly by the top-down processes, and to a lesser extent by the bottom-up processes.
3. From an analysis of eye movements, we learn that the graph processing strategy changes according to the prior knowledge that the subject has vis-à-vis the graph. With respect to familiar graphs and low-cognitive load graphs, the processing strategy is evidently affected by the top-down processes that drive the bottom-up processes, and the latter enable correct processing of the information presented in the graph. Despite this, there were subjects who had difficulty processing graphs, evidently due to the more pronounced effect of the bottom-up processes which lead and direct the visual approach as a result of various visual stimuli and cues which result in mistakes in processing the graph. We can see that the strategy for graph processing is different when the subject has no prior knowledge, the graph is new and unfamiliar to the subject. In such a situation, the graph processing is based on the bottom-up strategy and on previous strategies that fit other graphs that are familiar but that do not fit (i.e. will give mistaken results for) graphs where the cognitive load is high. From a qualitative analysis we can conclude that for correct graph processing visual attention should be focused on the visual information that leads to correct answers. But **bringing attention to areas which do not have information that is relevant to the correct answer, that is areas that are visually conspicuous, interferes with information processing.**
4. From the quantitative eye-tracking analysis we learn that the processing of the textual material is done in the first two seconds, and after that the processing varies according to the requirements of the task or goal. Similarly, the distribution of and fixation on the various areas is affected by the need to execute a cognitive task, and also by the degree of pretest direction for the graph

processing. But this difference does not exist in the area of the axis labels. In addition, almost no difference was found in the number and duration of fixations when we compare the results of graphs containing one curve with graphs of two curves. That is here, too, as in the case of behavioral results, we can see that the visual load has little effect on the graph processing strategy.

To summarize, we can assume that the strategy of graph processing takes place in a number of stages. The first stage takes place during the first two seconds in which the top-down process and the prior knowledge of the subject influence the bottom-up processes that include reading the textual material, and that enable the identification of the graph characteristics. After this stage, if the cognitive demands are low, the bottom-up processes continue to influence the turning of attention to fixations and their distribution, depending on the visual characteristics of the graph, and the tendency to read the text accompanying the graph. But a change takes place, and from the focus of attention on the titles, the attention moves to other textual information such as the labels and values/scale of the axes. But in the event that there is a cognitive demand, processing of visual information takes place, and the process of graph processing is affected by top-down processing which leads the bottom-up mode, and the attention moves to focus on the area of the curve, mainly at the expense of the areas of the graph titles.