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Understanding the Required Resources in Line Graph Comprehension

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Abstract

Visual line graphs are a prevalent form of communication as they provide a pictorial means to display relationships between entities. As such, understanding the cognitive resources required in processing line graphs would inform designers how to optimize the use of graphical displays. This study systematically investigated how graph task performance changes as a function of attention allocation (full or divided) and concurrent memory task (spatial or verbal). Twenty-four younger adults (mean age 19.2 years) completed either a trend comparison task or a point estimation task and a concurrent spatial or verbal task. Trend comparison performance did not significantly differ between the full and divided attention conditions; mean performance for all conditions was over 90% accurate. Interestingly, participants' point estimation performance was significantly better for the two divided attention conditions compared to the full attention condition which may be attributed to a motivational or stimulus effect. This study provides a base from which more research can be conducted to understand the verbal and spatial resources required in graph comprehension.

INTRODUCTION

Graphs are used in various domains by various users: Healthcare providers can monitor patient status using graphical displays, business people may use graphs to explain strategic decisions, and the popular media uses graphs to describe how changing one's diet can improve health. But how do people make sense of the lines and numbers displayed?

The visual line graph provides a method for pictorially representing relationships between variables (Gillan, Wickens, Hollands, & Carswell, 1998; Kosslyn, 1994). It is a prevalent form of communication used in many domains. A survey of graph usage in academic journals, magazines, and newspapers revealed 8159 graphs in 340 issues coded, and the average number of graphs per issue was 24.3 (Zacks, Levy, Tversky, & Schiano, 2002). Moreover, Zacks et al. found that line graphs comprised over 72% of the graphs used in academic journals and nearly 50% in magazines and newspapers. Of these line graphs, more than 90% were simple two-dimensional line graphs. This study will focus on two-dimensional line graphs, as they are a prevalent graph form used in various publications.

While it may seem that everyone can read and understand a line graph, research suggests that it is more than just simple pattern recognition (e.g., Shah & Carpenter, 1995). People do in fact make errors. Current models of graph comprehension suggest that the process is complex, incremental, and iterative (Carpenter & Shah, 1998; Freedman & Shah, 2002;

Pinker, 1990). Moreover, these models suggest an interactive top-down (knowledge driven) and bottom-up (data driven) process.

Factors that influence graph comprehension performance include the specific requirements of the task that is to be performed using the graph, the characteristics of the graph itself, the characteristics of the data presented in the graph, and the characteristics of the individual reading the graph (e.g., Peebles & Cheng, 2003; Shah, Freedman, & Vekiri, 2005).

Moreover, these factors have been shown to interact with each other and influence graph comprehension (Vessey, 1991). For example, studies have shown that line graphs support global tasks such as trend identification and trend comparison, whereas bar graphs support local tasks such as extracting point values (Zacks & Tversky, 1999). Because of the potential demands that these factors and their interactions can impose on readers' limited resources, these factors must be considered in graph comprehension. While the extant models of graph comprehension provide a basic foundation for understanding graph comprehension, the underlying cognitive resources involved in graph comprehension are not well understood.

As line graphs are composed of both spatial and alphanumeric components, it is likely that both spatial and verbal resources are required in line graph tasks. Bryant and Somerville (1986) described the spatial demands of reading a line graph, whereas other research has demonstrated that people can represent pictures verbally or spatially (MacLeod, Hunt, & Mathews, 1978). Based on this research, it is hypothesized that performance decrements will be seen in the divided attention conditions compared to the full attention condition when all resources can be devoted to the graph task.

The goal of this study was to understand the underlying verbal and spatial cognitive resources required in line graph comprehension. These insights can be used to support display design according to task demands and contexts. This study was intended to demonstrate that the task and available spatial and verbal resources must be considered in graph and general display design. This study investigated how performance on trend comparison and point estimation tasks changes as a function of attention allocation (full or divided) and concurrent memory (verbal or spatial) task.

METHOD

To investigate the verbal and spatial resources required in a trend comparison or point estimation task using a line graph, a dual-task paradigm was used based upon the multiple resources model (Wickens, 1984; 2002; Wickens & Hollands, 2000). This framework suggests greater interference between two simultaneously performed tasks to the extent they overlap. That is, the more resources that two tasks share, the greater the performance decrements will be in both tasks. It is important to understand the resources required in graph comprehension to provide more specific and predictive models of graph comprehension.

In the current study, participants performed either a trend comparison or a point estimation task while also performing a verbal or a spatial memory task under varying attentional

conditions (full or divided attention). This study focused on graph task performance as a function of concurrent memory task and attention allocation.

Participants

Twenty-four undergraduate students from the Georgia Institute of Technology between the ages of 18 and 28 years ($M=19.2$, $SD=1.53$) were recruited to participate in this study. There were 11 females and 13 males. Participants received either class credit or payment of \$10 per hour for their time.

Design

Graph task (trend comparison, point estimation) and attention to graph task (full attention, divided attention with concurrent spatial task, divided attention with concurrent verbal task) were manipulated within participants in a repeated measures design. Percent correct was used as the dependent variable for the graph trend comparison task. Root mean squared error (RMSE) was used as the dependent variable for the point estimation task. Performance on the spatial and verbal memory tasks was measured by percent correct. The dependent measures for the memory tasks were collected to check that the participants understood these tasks.

Materials

To assess participants' experience and familiarity with simple line graphs, they completed a line graph experience questionnaire based on one developed by Xi (2005) that investigated how person and task characteristics influence graph comprehension. Participants also completed an exit interview survey at the conclusion of the experiment to understand the strategies used throughout the experiment. However, these data will not be discussed in this paper.

Tasks

In the trend comparison task, participants were asked to identify which of four lines presented on a line graph was the steepest. All of the lines were increasing or decreasing, and no lines crossed over each other. It was explained to the participants that they were to identify the line that had the steepest slope. Each line was labeled one through four. In the point estimation task, participants were asked to identify the value of the point. Participants were shown a line graph also with four lines, either all increasing or all decreasing and no lines crossing over each other, with an asterisk on one of the lines. Participants were asked to find the value of the point.

For the spatial task, a four by three grid was constructed in which half of the squares were black and half were white. Participants were asked to memorize the grid and told that one of the black squares would be changed to white. Their task was to identify the square that had changed from black to white on the test grid. The verbal task was a series of six consonants presented in a two by three array. Participants were asked to memorize the letters and told that one of the letters would be changed to a new letter. Their task was to identify which letter had changed.

Participants were asked to complete either (1) the graph tasks and the verbal memory task simultaneously or (2) the graph tasks and the spatial memory task simultaneously. Participants were also asked to vary their attention given to the graph and memory tasks: Full attention was to be given either to the graph task or to the memory task, or participants were asked to attend to both the graph and the memory tasks simultaneously.

In the full attention condition, both tasks were presented; however, participants were instructed to attend only to the task of interest and to ignore the irrelevant task. Participants were only allowed to answer for the task of interest.

In the condition in which participants were instructed to attend to both the graph and the memory tasks simultaneously, they were instructed to vary the amount of attention given to each task at different levels. For instance, most attention was to be given to one task, while only a little attention was to be given to the other concurrent task and vice versa. Also, there was a divided attention condition in which participants were instructed to give equal attention to both tasks. The divided attention conditions were combined for this paper.

Procedure

The experimental task was conducted across two days with the concurrent memory task (spatial or verbal) counterbalanced across participants by day. Half of the participants began with the verbal task as the memory task on Day 1 followed by the spatial task on Day 2, whereas the other half received the opposite order. Participants completed both graph tasks (trend comparison and point estimation) each day and each session lasted approximately 90 minutes. Participants completed seven blocks with the verbal task and another seven blocks with the spatial task. There were sixteen trials per block for a total of 112 trials each day.

Upon completion of the line graph experience questionnaire, participants received instructions about the experimental task and were given practice. Participants were told how much attention (full or divided) to give to each task before each block. Using E-Prime Version 1.1 (Schneider, Esehman, & Zuccolotto, 2002), a memory task, either the verbal task or the spatial task, was first displayed. The memory task was presented until the participant pressed the spacebar followed by a 250 ms mask. Then, a graph question ("Which line is the steepest?" or "What is the value of the point?") was displayed. Once participants understood the graph question, they pressed the "c" key. A mask appeared for 250 ms, followed by the graph. Once an answer to the graph question had been determined, participants pressed the spacebar to move on to another 250 ms mask, and then on to the graph answer screen where participants typed their answer. The "Backspace" key could be used to change answers but only before the spacebar was pressed to submit an answer. Following a 250 ms mask, the verbal or spatial task question appeared asking the participant to select either (1) which letter was not in the original letter series or (2) which square was originally black that is now white. After participants entered their answer on a keypad, the sequence repeated. Feedback was given at the end of each trial. Upon the completion of the experimental blocks for Day 2, each participant completed an exit interview and was debriefed.

RESULTS

Performance on the memory tasks was first analyzed to ensure that participants understood these tasks. This served as a manipulation check. A one-way repeated measures ANOVA was conducted on the spatial task. A statistically significant difference was found in performance (percent correct) in the full versus divided attention conditions, $F(1, 23) = 64.84, p < .001$. A one-way repeated measures ANOVA was then conducted on the verbal task. Again, a statistically significant difference was found in performance (percent correct) in the full versus divided attention conditions, $F(1, 23) = 9.27, p = .006$. In both cases performance on the tasks in the full attention condition was better (higher percent correct) than performance on the tasks in the divided attention condition. These results suggest that participants understood how to do the spatial and verbal tasks and divided their attention when instructed to do so.

Because different dependent measures were collected for each graph task, percent correct for trend comparison and root mean squared error for point estimation, the study will be treated as two experiments that used the same group of participants for each graph task. A direct comparison between trend comparison and point estimation performance cannot be made.

Trend Comparison

A one-way repeated measures ANOVA was conducted for the trend comparison task (full attention on graph task, divided attention with spatial task, divided attention with verbal task) and no significant effects were found, $F(2, 22) = 2.77, p = .085$. *A priori* planned contrasts between the full attention condition and the two divided attention conditions were then conducted. No significant differences were found ($p = .71$ for the spatial task; $p = .08$ for the verbal task). These results were unexpected as it was predicted that trend comparison performance at the full attention condition would be better than in the divided attention conditions. Instead, performance was high for both the full and divided attention conditions. See Figure 1.

Point Estimation

The one-way repeated measures ANOVA for the point estimation task (full attention on graph task, divided attention with spatial task, divided attention with verbal task) was significant, $F(2, 22) = 14.30, p < .001$. *A priori* planned contrasts were then conducted between the full attention condition and the two divided attention conditions. A significant difference was found between full attention on point estimation task and divided attention with spatial task, $t(23) = 4.47, p < .001$. A significant difference was also found between full attention and divided attention with the verbal task, $t(23) = 5.30, p < .001$. Interestingly, participants performed better (lower RMSE) on the point estimation task when their attention was divided. See Figure 2.

DISCUSSION

Current models of graph comprehension provide a basic foundation for understanding graph comprehension. However, the underlying cognitive resources involved in graph comprehension are not well understood. The goal of this study was to understand the role of

verbal and spatial cognitive resources in line graph comprehension. This study investigated whether performance on trend comparison and point estimation tasks changes as a function of attention allocation and concurrent memory (verbal or spatial) task.

The results presented from this study support previous research that has found tasks such as trend comparison are supported by line graphs (Zacks & Tversky, 1999) as mean performance was over 90% accurate for all conditions. However, the null results for trend comparison performance at full versus divided conditions were unexpected as it was predicted that performance on the trend comparison task would be best for the full attention condition, followed by the divided verbal condition, and lastly by the divided spatial condition. The results suggest that the experimental tasks may not have been challenging enough for the participants and led to a data limited situation. Alternatively, it is possible that because line graphs support trend comparison, a resource limited situation could be difficult to create. To investigate these potential explanations of the findings, future studies can systematically manipulate the levels of difficulty of both the trend comparison task as well as the memory tasks.

The significant results for point estimation performance at full versus divided conditions were intriguing: Participants' point estimation performance was best for the two divided attention conditions compared to the full attention condition. These counterintuitive findings may indicate that participants became more engaged with the task in the divided attention condition. Alternatively, it could be that the point estimation tasks were more difficult in the full attention condition due to a stimulus effect but initial analyses suggest that is not the case.

Future research efforts in this domain are warranted. Studies should be designed to compare a broader range of graph types, difficulty level, and concurrent task demands.

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Figure 1.
Percent correct for trend comparison task as a function of attention condition. Error bars represent standard error.

Figure 2. Root mean squared error for point estimation task as a function of attention condition. Error bars represent standard error.