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ABSTRACT

This study examined problem solving as a function of display type (table/graph) and numeric function (linear/nonlinear) in four problem solving domains. Twenty-two stimulus problems were developed, and line graph and table displays were constructed for each problem. Half of the displays contained linear numeric functions and the other half contained nonlinear numeric functions. Each display was accompanied by four questions which required: (1) the location of a specific value; (2) trend analysis; (3) data interpolation; and (4) a forecasting decision. Each of the 109 subjects completed six practice and 16 experimental problems. Although overall decision time between graphical and tabular displays did not differ, the subjects performed better with tabular displays when locating specific values and better with graphical displays when interpolating, forecasting, or judging data trends. Overall, subjects performed faster and more accurately for both types of display when solving problems using nonlinear functions. Tables of experimental results are appended, and 25 references are listed. (MES)

Problem Solving Performance and Display Preference for Information Displays Depicting Numerical Functions

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As the amount of information accessible via computer systems increases, so do problems associated with presenting information that can be assimilated easily and accurately. Many researchers advocate the graphical presentation of information to allow for effortless perception and organization of information. Research in many diverse areas has focused on determining effective information presentation. Educational researchers compared graphical and tabular displays in classroom settings (Rigney & Lutz, 1976; Washburne, 1927) and results indicate pictorial or graphical representations effectively aid problem solving performance. Statisticians contributing to this area have concentrated on design aspects of graphs and tables, and have produced manuals describing design guidelines. Research generated by statisticians (Carter,1947;1948a;1948b) indicates that graphs enhanced performance for tasks requiring data interpolation, while tables enhanced performance for tasks requiring the reading of specific values. The major focus from the Human Factors perspective concerns general design issues, such as brightness, contrast, and color. Tullis (1981) compared tabular and graphical displays for a telephone diagnostic task and found no differences for type of display. Schutz (1961) compared line, vertical bar, and horizontal bar graphs for a trend analysis task and found subjects performed best with the line graph, followed by the vertical bar and lastly with the horizontal bar graph.

Researchers in the area of graphical perception are developing a scientific foundation for data analyses and presentation based on the visual processes involved in graph interpretation. Cleveland and McGill (1986;1985;1984) identified a set of elementary perceptual tasks used by individuals when interpreting graphs. These tasks include determining graph positions on common and non-aligned scales and judgements of length, direction, angle, area, and volume. Through experimentation, these researchers determined which tasks individuals performed most accurately. They reasoned that by using graphical representations that maximize an individual's graphical capabilities, the ability to detect patterns and organize information is enhanced. They reported that individuals perform more accurately at determining graph positions using a common scale rather than a non-aligned scale, thus, graphs should be developed using a common scale.

Related research has also been generated by the Management Information Systems discipline (cf. DeSanctis, 1984 for review). Generally this research reports conflicting findings. Several studies indicate a graphical presentation of information facilitates performance (Benbasat & Schroeder, 1977; Lusk & Kersnick, 1979; Zmud, 1978).

However, one study conducted by Remus (1984) reported performance benefits using a tabular display. Still other studies have reported mixed performance results (Lucas, 1981; Benbasat & Dexter, 1985; Powers, Lashley, Sanchez & Shneiderman, 1984). It is apparent from this literature that the effect of tabular and graphical displays is dependent on the type of task.

Recently efforts have been made to vary type of task systematically (Dickson, DeSanctis, & McBride, 1986; Jarvenpaa & Dickson, 1988; LaLomia & Coovert, 1987). This research demonstrates that graphs facilitate the speed and accuracy of performance for tasks involving rapid summary of information, forecasting, interpolation, and trend analysis while tables facilitate tasks requiring the use of specific values.

Taken together, this research neglects the issue of how information represented by the data may effect problem solving performance. Differences in problem solving performance as a function of the progression of numbers represented by the data has been reported with tables and graphs of exponential growth curves (Timmers & Wagenaar, 1977). For both increasing and decreasing monotonic functions, subjects underestimated growth. However, subjects performed better with descending rather than ascending number series. In a similar study, Mims (1984) used numerical and spatial displays of four types of numerical relationships (x>y, x>y+2, x>2y, and x>2y+2). Subjects using spatial displays with x>y numerical functions reached criterion faster. Based on this research, it is expected that different numeric functions represented in a table or graph may affect problem solving performance.

The present research examines how problem solving is affected by both display type and numeric function. Problem solving performance is examined as a function of display (table/graph) and numeric function (linear/nonlinear) in four problem solving domains (locate number, interpolate, trend analysis, forecast). Subjects viewed graphs and tables depicting a linear or nonlinear progression of numbers and used the display to solve problems from the four domains. Measures of problem solving time, accuracy, and display preference were collected.

Method

Materials

Twenty-two stimulus problems were developed by modifying information from the Graduate Record Exam (Brownstein & Weiner, 1981; 1985) and Scholastic Aptitude Test (Brownstein & Weiner, 1983). Two displays were constructed for each problem. One display depicted the information as a line graph and the other displayed the information as a table. One-half of the displays contained linear numeric functions and the other half contained nonlinear numeric functions. A nonlinear function was a random ascending and descending sequence of numbers while the linear functions were all ascending number functions. Each display was accompanied by four questions which required: (1) the location of a specific value, (2) trend analysis, (3) data interpolation, and (4) a forecasting decision.

Display type and stimulus problem was randomized across subjects.

Design

The experimental design was a 4 (question type) x 2 (display type) x 2 (numeric function) factorial. There were four question types: locate number, trend analysis, interpolate, forecast. The two types of display were tabular and graphical, and the two types of numeric functions were nonlinear and linear. Each factor was manipulated within subjects.

Procedure

One hundred and nine individuals with 20/20 vision served as research participants, each tested individually in a 40 minute session. Participants used a table or graph to solve a series of problems. They were instructed to read each problem and based on the tabular or graphical information choose one of the four alternatives. Once the table or graph was displayed, an internal computer clock was initiated and remained running until subjects responded. All subjects completed 6 practice and 16 experimental problems.

Results

Mean decision time for correct responses and mean number of incorrect responses was calculated for each condition (Table 1). Overall decision times were similar for tabular (19.17 sec) and graphical (19.12 sec) displays . For each problem domain decision times differed as a function of display. The mean time for locating a number was much slower with graphical displays (13.04 sec) than with tabular displays (8.63 sec). However, with interpolation problems, subjects were quicker using graphical (19.92 sec) as compared to tabular displays (22.41 sec). Trend analysis problems also resulted in slightly faster performance with graphical rather than tabular displays (16.18 sec vs 17.44 sec). With the forecasting task, again subjects were slightly faster with the graphical display (27.32 sec) than with the tabular display (28.19 sec). Overall, subjects were slower with linear functions (20.85 sec) compared to nonlinear functions (17.43 sec).

These results were confirmed with analysis of variance. There were main effects of question [$F(3,324)=170.71$, $p<.0001$] and function [$F(1,108)=46.16$, $p<.0001$]. Interactions were specified between question and display [$F(3,324)=7.33$, $p<.0001$], question and function [$F(3,324)=10.42$, $p<.00001$] and a three way interaction among display, question, and function [$F(3,324)=8.10$, $p<.0001$]. The significant three way interaction is due to the graphical/forecasting condition where linear functions produced significantly faster decision times (24.76 sec) than nonlinear functions (29.88 sec). The Fisher's LSD was 2.84. All other conditions showed the opposite effect, that is, subjects performed quicker with nonlinear functions.

The error data (Table 2) showed that overall more errors were made with tabular as compared to graphical displays (1.44 vs 1.22). This was also true for all problem domains.

Subjects committed more errors with linear functions (1.64) than with nonlinear functions (1.02). An analysis of variance showed main effects of display [$F(1,108)=24.06$, $p<.00001$], question [$F(3,324)=48.80$, $p<.0001$], and function [$F(1,108)=192.85$, $p<.0001$]. Interactions were specified between question and display [$F(3,324=4.26$, $p<.0006$], question and function [$F(3,324)=103.81$, $p<.00001$], and a three way interaction among display, question, and function [$F(3,324)=2.77$, $p<.04$]. The three way interaction was due to the forecasting condition where linear functions produced significantly fewer errors than nonlinear functions. The Fisher's LSD was .19. All other conditions showed the opposite effect, that is, subjects committed fewer errors with nonlinear functions.

Subjects rated display preference for each problem type on a nine point scale: one reflecting a tabular display preference and nine reflecting a graphical display preference. Subjects indicated a strong preference (3.00) for the tabular display when they had to locate a specific number and a slight preference (3.76) for the tabular display when they performed a trend analysis. A slight preference for the graphical display was reported by subjects with the interpolation (5.81) and forecasting (5.57) tasks. An analysis of variance showed an effect of question [$F(4,380)=26.76$, $p<.0001$]. The tabular preference for the locate number and trend analysis tasks was significantly different from the other two tasks preferences (LSD=.62).

Discussion

Overall decision time between graphical and tabular displays did not differ. However, as suggested by previous research (LaLomia & Coovert, 1987) the important variable is not simply the display type but the nature of the problem to be solved. This study shows that subjects perform best with tabular displays when locating specific values, but when they must interpolate, forecast, or judge data trends they perform best with graphical displays.

The main focus of this study was on how the progression of numbers represented by the data, the type of display, and the problem domain affect problem solving performance. The results showed large performance differences due to the type of numeric function. Overall, subjects were significantly faster and more accurate when solving problems using nonlinear functions. This was true for both display types and all problem types with one exception. This exception caused the significant interaction among display, question, and function. This interaction was due entirely to the graphical/forecasting condition where subjects were faster solving problems with linear functions. In all other conditions subjects solved problems faster using nonlinear functions. Future research should examine this issue more fully exploring moderators of this finding.

Interestingly, subjects solve problems quicker and more accurately with nonlinear data functions for both tabular and graphical displays. This result indicates subjects may be apprehending global information about the linearity of the number progression with both tables and graphs. For graphs it is clear that linear information is immediately and effortlessly extracted from the display due to its graphical nature. However, it is surprising that linear information is also extracted from the tabular displays. Perhaps the perceptual system preattentively extracts linear information when presented with a set of numbers.

The results clearly indicate that nonlinear data sets enhance problem solving performance. Two speculations are offered for this finding. First, nonlinear data functions may allow for easier visual extraction of data elements because the differences among the data elements are more clearly indicated in a nonlinear function. Second, we know that the perceptual system seems to be constructed for detecting change or differences in the environment. Perhaps nonlinear functions capitalize on the perceptual system's abilities because nonlinear functions are continuously changing direction, that is, the numbers represent random ascending and descending sequences. A future study will look at problem solving performance as a function of the amount of change for a nonlinear progression of numbers.

This research examined how the type of display and the type of numeric function represented by the data effects problem solving performance. The graphical presentation facilitated performance with problems involving interpolation, trend analysis, and forecasting. The tabular presentation facilitated performance when the problem required identifying specific values. The type of numeric function represented by the data also had a strong effect on problem solving performance. Performance was quicker and more accurate with nonlinear as compared to linear functions in the location, trend analysis, and interpretation tasks. Many directions for future research have been indicated. These include the examination of the forecasting task to determine why linear functions facilitated performance. Also, further experimentation is warranted regarding the issue of whether linearity information is extracted from number progressions preattentively.

Table 1. Decision time (seconds) for the graphical and tabular displays by linear and nonlinear functions.

	Tabular			Graphical		
	Linear	Nonlinear	Mean	Linear	Nonlinear	Mean
Locate Number	9.62	7.64	8.63	15.01	11.06	13.04
Interpolation	24.24	20.57	22.41	23.58	16.26	19.92
Trend Analysis	19.47	15.40	17.44	20.47	11.88	16.18
Forecasting	29.62	26.75	28.19	24.76	29.88	27.32
Mean			19.17			19.12

Table 2. Mean number of incorrect responses for the graphical and tabular displays by linear and nonlinear functions.

	Tabular			Graphical		
	Linear	Nonlinear	Mean	Linear	Nonlinear	Mean
Locate Number	1.55	.75	1.15	1.39	.50	.95
Interpolation	2.17	.99	1.58	2.20	.90	1.55
Trend Analysis	1.91	.89	1.40	1.36	.67	1.02
Forecasting	1.47	1.78	1.63	1.10	1.64	1.37
Mean			1.44			1.22

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