TESTING THE EFFECTIVENESS OF SONIFIED GRAPHS FOR EDUCATION: A PROGRAMMATIC RESEARCH PROJECT

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ABSTRACT

This programmatic research project builds on results from research on data sonification and from studies investigating comprehension of visual graphs. The purpose of the project is to explore the effectiveness of using sonified graphs of real data sets from disciplines to which students are exposed during academic courses. The primary question is whether sonified graphs can increase the comprehension of graphed data for students. The secondary question is whether stereo or monaural sonifications are most effective for graph comprehension. The third and final question of this project is whether sonified graphs with rhythm markers result in better comprehension than sonified graphs without them. The project consists of three laboratory experiments that explore whether students can match auditory representations with the correct visual graphs, whether they can comprehend graphed data sets more effectively by adding sonified components, and whether they can be trained to use sonified graphs better with practice. Results could provide new methods for teaching students with different learning styles quantitative skills in educational settings from kindergarten through college. They could also be extended to assist in teaching students with visual impairments about graphed data sets.

1. INTRODUCTION

There has been a good deal of research performed to determine how people comprehend visually graphed data. Researchers have examined the visual components of graphs [1][2][3][4], specific cognitive processes involved in graph comprehension [5][6][7], and cross-cultural and age factors that affect understanding of graphs [8][9]. Research in this area has progressed to the point that investigators are proposing full-scale theories of graph comprehension [10].

In contrast, research on the effectiveness of sonified graphs is in its infancy. There has been some work using simulated data sets with different types of graphs, including line graphs [11], scatterplots [12], and box-whisker plots [13] to compare visual and sonified graph comprehension of basic distribution properties of the graphed data sets. Other researchers have focused on sonified graphs of complex data sets in research settings [14][15][16]. However there has been little research to date investigating using sound in addition to visual displays in education. Therefore, the present research program was developed to extend the research on visual graph comprehension and sonified graphs to the types of data students are exposed to during their coursework.

The project consists of three studies: matching visual and sonified graphs; comparing comprehension of visual and sonified graphs, and practicing the use of visual and sonified graphs. In each of these studies, there is an emphasis on using real data sets from a variety of disciplines. The studies are also designed to test the effects of stereo sound presentation, and the second and third studies add a test of the effects of a rhythmic component to sonified graphs. Even though the results of each study can stand independently, the entire project is designed so that it addresses fundamental questions about using sonified graphs of real data sets for students.

2. STUDY 1 –MATCHING VISUAL AND SONIFIED GRAPHS

The graph matching study was designed to provide basic information about whether students could match auditory versions of graphs with the visual graphs of real data sets. It was also designed to compare stereo and monaural sonifications of graphs. The results from this study provide information about how well students understand intuitively the underlying assumptions of sonified graphs as well as how performance varies for stereo and monaural graphs.

2.1. Participants

The participants in this study were 54 college students with normal vision and hearing. They ranged from 19 to 23 years of age with a mean age of 19.5. Three of the participants were excluded from the data set due to incorrect responses on all three practice sets. The researchers believed this indicated that these individuals were not taking the task seriously and should not be included in the analysis. Thus the final number of participants included was 51.

2.2. Stimuli

The data sets for the 20 graphs (8 bivariate and 12 multivariate) used in the study were taken from DASL, an on-line database of real data sets. Data were chosen to reflect as many different disciplines as possible in order to maximize the variability of the graphs and to reflect as much as possible the types of information a student would be exposed to in college or high school courses. Both bivariate and multivariate data sets were used, and they were
graphed using CricketGraphic and sonified using Metasynth and SoundEdit software packages.

The synthesized sound used for the bivariate graphs was a flute while the multivariate graph sounds were represented auditorily by the synthesized flute and a synthesized bassoon to maximize the discriminability of the two auditory stimuli. All graphs had sonifications that fell within a three-octave range.

The visual graphs had black backgrounds with white dots or lines for the bivariate graphs and red and green dots and lines for the multivariate graphs (Figures 1 and 2 provide examples in black and white of the graphs used). The auditory representations of the graphs used the X-axis as time and the Y-axis as frequency with a one to one correspondence between the plotted data and the tones for all graphs. Sound for the bivariate graphs was presented to both ears monaurally with the sound source appearing to be directly in front of the participant. The sonified versions of the multivariate graphs were presented in stereo with the variable in red in the right channel and the variable in green in the left channel. As mentioned previously, the sounds for the multivariate graphs were further distinguished by different timbres. All sounds were presented to participants using headphones.

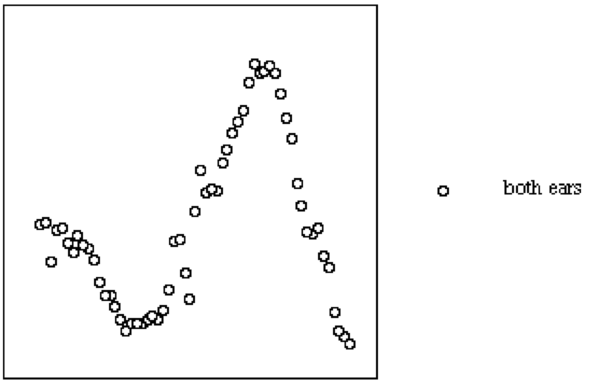

Figure 1. Example mono/bivariate graph of live births per 10,000 women in the USA from 1917 to 1975.

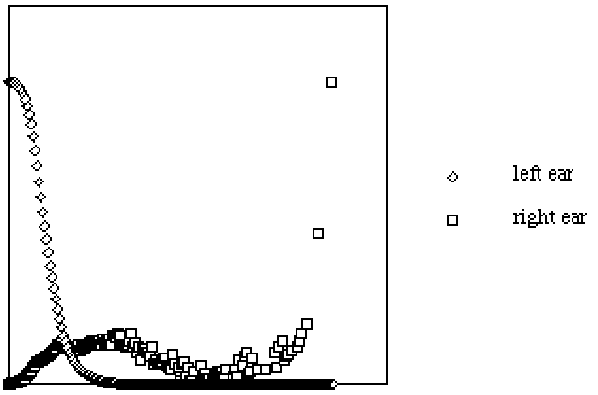

Figure 2. Example stereo/multivariate graph of med fly mortality rate.

2.3. Procedure

HyperCard was used for the 1 1/2 hour data collection procedure, and the program began with a set of demographic questions including age, sex, and musical ability. The program was designed to present participants with a total of 3 practice trials, using simplified graphs, followed by 24 test trials. The test trials consisted of the 20 graphs from the real data sets with 2 repeat trials and 2 trials that had no matching graph on the screen for the sound. Presentation order of the sounds and graphs was randomized across participants. During both the practice trials and the actual data collection trials, the display presented four graphs (one target graph and 3 randomly chosen graphs), while a sound was played. The participant's task was to choose the graph he or she believed was the matching visual graph for the sound by clicking on the graph in the display. Participants could choose to play the sound as many times as they wished to assist them in making a match by pressing a button on the screen (see Figure 3 for an example of the screen used for the visual graph presentation for each trial). All participants were told that accuracy was the most important aspect of the task, but that they should still work as quickly as possible within this constraint.

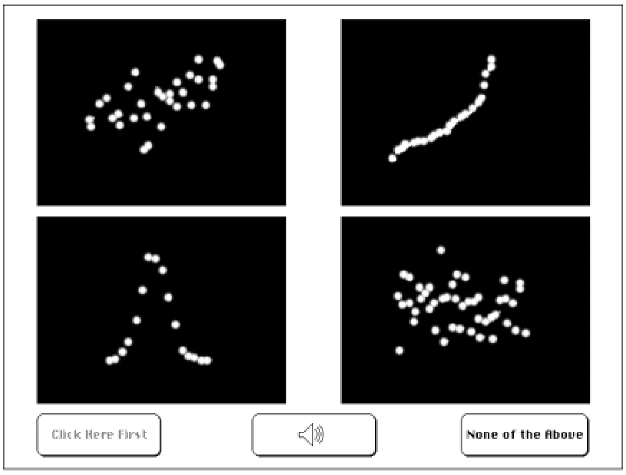

Figure 3. Example test trial screen for the matching procedure.

2.4. Results and Conclusions

The independent variable used for the main analyses was sonification type, with two levels (stereo versus monaural presentation). The dependent variables collected included number of correct matches, reaction time for each choice, and number of times the sonified graphs were played. In addition, a confusion matrix was made for the matches between the sonified and visual graphs. The following presentation of the results will refer to the multivariate graphs and the bivariate graphs using the type of sonification, stereo and mono, respectively.

One demographic variable, musical ability was also included in the overall analysis of the data. Participants were asked about whether they played a musical instrument or sang, and if so, for how long had they done either of these activities. This was designed to get a general idea of the musical experience/ability of the participants. Results showed no differences in responses for any of the variables for participants with and without musical experience; thus this variable was not considered in the other analyses.

Overall accuracy for all participants in making matches was good. As can be seen in Figure 4, which shows the number of participants who correctly identified each graph, the number of participants who correctly matched the sonification with the graph ranged from 28 to 49 out of 51 participants with a mean of 42.3 correct matches for all graphs.

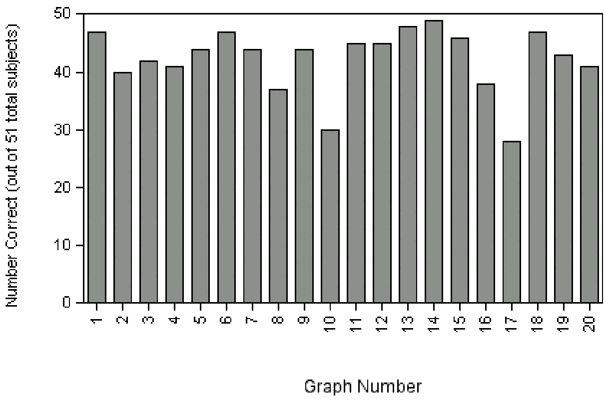

Figure 4. Graph of total correct matches across subjects for visual and sonified graph by individual graphs.

The graphs with the lowest accuracy rate were Graph 10 and Graph 17, with 30 and 28 correct matches, respectively. Examination of the visual graphs revealed that both of these graphs were stereo-graphs, and that they are both very diffuse and lacked a definite shape for the data (see Figure 5 for Graph 10). In addition, inspection of the confusion matrix suggests that these graphs were confused most often with other stereo-graphs that also had widely dispersed data points and no easily discernable "envelope".

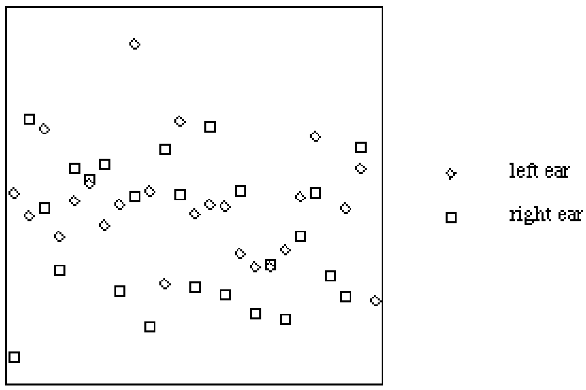

Figure 5. Example of one of the graphs subjects had difficulty matching with its sonification (Graph 10).

Within groups ANOVAs were used to test mean differences for number of correct matches, reaction time, and the number of times the sonified graphs were played. A significant difference was revealed for the mean number of correct matches between the stereo- and mono-graphs, $\underline{F}$ (1, 7) = 7.54, $\underline{p}$<.05, $\underline{MSE}$ = 11.96. The mono-graphs ($\underline{M}$=45.88, $\underline{SD}$=1.64) were matched correctly with their visual counterparts more often than the stereo-graphs ($\underline{M}$=41.13, $\underline{SD}$=5.79). The test of reaction times showed that the stereo- graphs ($\underline{M}$=710.42, $\underline{SD}$=69.35) took longer to match than the mono-graphs ($\underline{M}$=586.76, $\underline{SD}$=79.94), $\underline{F}$(1,7)=172.15, $\underline{p}$<.001, $\underline{MSE}$=355.32, and it was also found that the stereo- graphs ($\underline{M}$=2.01, $\underline{SD}$=1.65) were played more times than the mono-graphs ($\underline{M}$=1.80, $\underline{SD}$=1.86), $\underline{F}$(1,7)=108.57, $\underline{p}$<.001, $\underline{MSE}$=.002.

These results suggest that the subjects had good performance on the matching task overall. However considering the number of correct matches, the reaction times and the number of times each sound was played, the bivariate graphs were easier to match with their sonified representations than the multivariate graphs. This suggests either that processing of stereo stimuli is more time consuming and difficult than processing monaural stimuli or that multivariate graphs are more difficult to process visually than bivariate. There could also be an interaction between the two types of stimuli that could lead to longer processing as well. This study was not designed to separate the visual from the auditory effects; however, it does not seem surprising that cognitive processing of more stimuli should take longer in general, regardless of the modality type. It is also clear that distinctiveness of the "shape" of the graph, whether this is done using either sound or vision, has an impact on correct matching. Finally, these results provide support for the continued investigation of sonification for real data sets since the overall performance suggests that students had little difficulty understanding the relationship between the auditory and visual stimuli.

3. STUDY 2 – COMPARING COMPREHENSION OF VISUAL AND SONIFIED GRAPHS

The graph comprehension study is designed to assess comprehension of information presented in graphed data sets comparing visual graphs with two types of sonified graphs. One type of sonified graph is the same as was used in the previous study while the second type adds a rhythm component that indicates the position of the tick marks on the X-axis within the sonified graph. The addition of rhythm may act as an additional auditory referent for the listener to assist in tracking the auditory display in relation to the visual graph. Questions answered by the participants about the information presented in the graphs vary in level of difficulty as well as the types of responses participants make.

3.1. Participants

A similar sample of college students is being used in this study. Participants are randomly assigned to one of three conditions (visual graphs only, visual graphs with sonification, and visual graphs with sonification and rhythm markers). Pilot data collection began in December, 2000 and continues to date. Thus, the current report will only include a description of the methods and proposed analyses.

3.2. Stimuli

The stimulus set consists of 28 graphed data sets taken from the DASL database. As in Study 1, the real data sets were selected to maximize the disciplines represented and the variability in the graphs. The 28 graphs consist of 14 line graphs and 14 scatterplots, and for both the line graphs and scatterplots, 7 of the graphs are bivariate graphs and 7 are multivariate graphs. There are three different conditions: visual graphs only, visual graphs with sonification, and visual graphs with sonification and rhythm markers. Participants in the visual graph condition are presented with standard line graphs and scatterplots. As in Study 1, the bivariate graphs have white lines or dots on a black background, while the multivariate graphs have red and green dots and lines to designate the variables. Participants in the other two conditions have sound added to the visual graphs. In the sonified graph condition, participants hear digitized instruments (the flute for monaural graphs and the flute and bassoon for the stereo-graphs) that use the X-axis as time and the Y-axis as frequency. In the sonified graph condition with rhythm markers, the participants have both the visual representation and the sound as well as a rhythm marker (a synthesized snare drum) that indicates the tick marks on the X-axis. Different timbres and the presentation of separate variables to the right and left ears are used to indicate multiple variables as was done in the previous study.

For each graph, participants are presented with a written description of the data set and why it was collected prior to viewing the graph. Then each graph is presented with four questions that vary in the level of cognitive complexity (ie, specific data points, comparison of data points, trends in the graph, and interpolation/extrapolation of data points)[17]. Figures 6 and 7 provide examples of data descriptions and of a graph with one type of question.

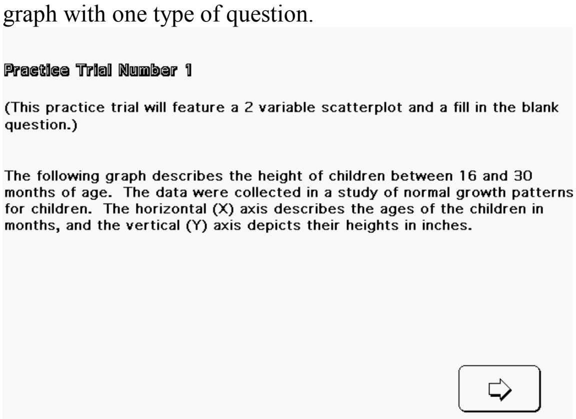

Figure 6. Example screen for data description of graphs.

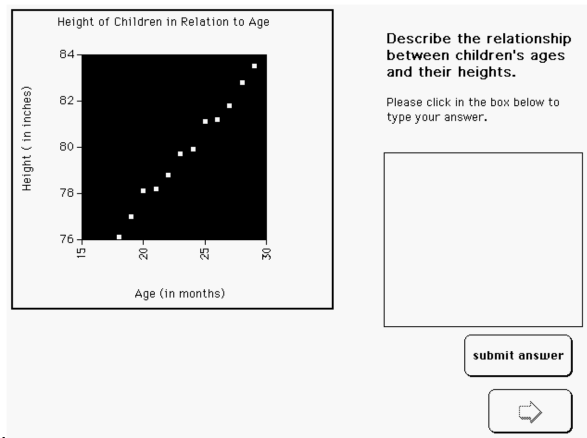

Figure 7. Example screen for the graphs and questions.

3.3. Procedure

HyperCard is being used as the data collection software package, and participants in each condition are given one of two random presentation orders of the graphs. Participants begin the 1 1/2 hour session by filling out a questionnaire with demographic questions that include information about musical ability and experience with graphs. Then participants are given 4 practice trials to familiarize them with the question types, the graph presentation, and other aspects of the procedure. Once they have completed the practice trials and asked any questions they may have, formal data collection begins. For the test trials presentation order of question types is randomized across participants. The participants answer the questions in multiple choice, fill-in-the-blank, and open-ended formats. Each graph has 4 trials. For each graph, the participant first reads the description of the data. Then on the following screen, the participant first sees one question for 5 sec without the graph. The graph then appears for 15 sec, and during this time, the participant is instructed to determine what the correct answer should be. Participants are not allowed to respond until the graph disappears after the 15 sec interval. This is repeated for the 3 additional trials for that graph with a different question type and question format for each trial. The procedure is then repeated for the following graph. Thus, participants complete a total of 112 questions during the experimental session. They are given two 2-min breaks during the session to reduce fatique. Following the completion of the HyperCard program with the graphs, participants fill out a follow-up survey that asks about the difficulty of the tasks, the strategies used to understand the graphs, and, for those participants in the sound conditions, the usefulness of the sounds for them during the trials.

3.4. Possible Results and Conclusions

There will be three dependent variables collected: number of correct responses to questions for each graph type (scatterplot and line graph), number of correct responses to questions for bivariate and multivariate graphs, and number of correct responses for each question type (specific data points, comparison of data points, trends in the graph, and interpolation/extrapolation).

The Omnibus analysis will be performed as a MANOVA using the condition (visual graphs only, visual graphs with sonification, and visual graphs with sonification and rhythm markers) as the between groups variable and graph type and question type as within group variables. The analysis will also examine whether any demographic variables, such as experience with music or with science courses that require work with graphs, have an impact on the performance of the task. Results from this study will be used to determine the final design of the third study in the project. Currently, we are finishing with the collection of pilot data on this study. We will begin the full-scale data collection in the fall of 2001.

4. STUDY 3 - PRACTICING THE USE OF VISUAL AND SONIFIED GRAPHS

The third study in this research program is designed to examine whether practice can lead to better performance in graph comprehension for visual and sonified graphs. The study will use similar methods as in Study 2, but participants will have repeated exposure to the graphs over a period of 6 weeks.

4.1. Participants

The same type of sample of college students will be used for this study. Students will be paid for their participation to help assure that they will complete the full 6-week program, which will require them to practice using the graphs twice weekly for a total of 12 sessions. They will also be randomly assigned to one of the same three conditions as in Study 2 (visual graphs only, visual graphs with sonification, and visual graphs with sonification and rhythm markers). Each participant will remain in only one condition throughout the longitudinal study.

4.2. Stimuli

Stimuli will be the same type as found in Study 2. Data sets will be obtained from a variety of sources due to the large number of graphs needed (approximately 20 graphs per session resulting in 240 graphs total). The same three conditions will be used and the same types of questions as in Study 2.

4.3. Proposed Procedure

The hour long sessions will be performed using a computer program to present the stimuli and the questions as in the previous two studies. Participants will answer demographic questions during the first session and a follow-up questionnaire after each session to rate the perceived difficulty of the tasks and to describe any change in their strategies in working with the graphs. During each session, participants will work only with the types of graphs in the condition to which they were assigned.

4.4. Possible Results and Conclusions

Data will be analyzed using the same statistical procedures outlined in Study 2. In addition, repeated measures analyses will be used to determine if there is any change in performance across the 12 sessions. We would expect to see improvement for all three conditions with practice. However, we hypothesize that the change will be greater for the two conditions with sound, since the students would not have had previous exposure to such displays.

5. CONCLUSIONS

One purpose of this series of studies is to test the effectiveness of using sonified graphs for data sets students are exposed to in their coursework. Students in many types of classes must be able to understand information presented in graph form, and the addition of sound to the visual graphs may assist in this task. One especially important component of this project is testing using a longitudinal design. People need practice in order to perform most tasks effectively; thus, in order to determine whether sonified graphs are useful, more than one exposure to this type of stimulus is necessary.

Two other major elements of this project are to test stereo and mono sonifications and to examine two different types of auditory display. To date, there have been no studies to the authors' knowledge that have incorporated a rhythm component to the sonification of graphs. This element should make the graph more "musical" and thus may assist in people's ability to follow the auditory stream that is representing the visual graph.

While the work on this project is still in the beginning stages, we feel that it is important to provide an example of a programmatic approach to sonified graph research since past work has focused primarily on one-shot studies. Future work in this area in our laboratory will focus on working with younger children and students with visual impairments. We are currently developing collaborative efforts with the public schools in the area and with the Indiana School for the Blind in Indianapolis, IN to continue this research with these special populations.

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