A SUGGESTED AGENDA FOR AUDITORY GRAPH RESEARCH

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ABSTRACT

This paper presents one option for a research agenda for future work in auditory graphs. The main agenda items suggested are effectiveness of auditory graphs; sonification tools; role of memory and attention; real-world applications; longitudinal studies of learning; and neurophysiological research. A brief review of past research in each area is given to provide general information about relevant studies and is meant to serve as a starting point rather than as a comprehensive overview of the literature on auditory graph studies.

1. INTRODUCTION

Due to the ubiquitous use of visually graphed data, cognitive psychologists and educators have performed numerous studies to determine the cognitive processes involved in reading, comprehending and interpreting graphed data as well as to discover how best to teach the skills of reading, understanding, using, and producing visual graphs. Researchers interested in these phenomena have examined the visual components of graphs [1][2][3][4][5], specific cognitive processes involved in graph comprehension [6][7][8][9][10][11], and cross-cultural and age factors that affect the understanding of graphs [12][13][14]. Research in this area has progressed to the point that investigators are proposing full-scale theories of graph comprehension [15][16]. However, research devoted specifically to the investigation of sonifying graphed data is in its infancy compared with the extensive literature and knowledge base available for visually graphed data.

Over the past 10 years the area of general sonification research has received growing interest from investigators in a variety of fields, including perceptual psychologists, engineers, computer programmers, and computer hardware designers. Since computers now are routinely equipped with sound cards and speakers, sound can be added easily to a wide variety of data. There are already some compelling examples of general sonification tools for computers and other devices. The most well known example would be the Geiger counter that "clicks" in response to radiation levels. The Geiger counter is also important because research has demonstrated that the auditory feedback alone from the Geiger counter is better than visual or combined visual-auditory displays [17]. Similar sonification projects that have been developed include exploring infrared spectrometry data [18] and monitoring human physiological processes [19][20] through sound.

Research focusing specifically on auditory graphs has also seen increased activity during this same time frame, but in order for the work to progress in an efficient manner so that it can begin to approach the current knowledge available for visual graphs, it is time for a review of the past work and for a discussion of appropriate plans for future research efforts. Thus, the purpose of the present paper is to briefly explore some of the past research on auditory graphs and propose one possible research agenda for future work in this area. This agenda includes six specific areas of interest for auditory graphs: general effectiveness; sonification tools; role of memory and attention; real-world applications; longitudinal studies of learning; and neurophysiological research.

2. GENERAL EFFECTIVENESS

Investigating the effectiveness of using sound alone or as an adjunct to visual graphs has been the most active area of research for auditory graphs. For example programmatic research by Flowers and his colleagues has shown through a series of studies that auditory and visual displays of time series data [21], distribution of single samples [22][23] periodic numerical data [24] and bivariate scatterplots [25] are basically equivalent in terms of subjects' abilities to identity and understand the data distributions. Walker and his associates have examined individual differences in the ability to comprehend auditory graphs [26] and the effects of sonified labels, axes, and tickmarks on the perception of auditory graphs [27]. Other researchers have also had encouraging results from using sound for graphed data [28][29][30][31].

In addition, researchers have also investigated the psychoacoustic parameters that affect the construction and the subsequent perception of auditory graphs [32][33]. Finally recent work has also brought into context the importance of dynamic human interaction when exploring datasets with sound [34].

Suggestions for future work on general graph effectiveness include concentrating first on synthesizing and consolidating previous work in the area to determine the most appropriate next steps. Research investigating psychoacoustic properties requires additional exploratory work building on both previous work specifically with auditory graphs and on established psychophysical properties of general sound perception.

3. SONIFICATION TOOLS

One of the major obstacles to constructing auditory graphs has been the lack of available software that can easily sonify graphed data using either data sets or visual versions of graphs. This is especially problematic if the user wants to produce such graphs quickly for either educational or data exploration purposes. There have been a number of tools created by researchers for general sonification, as can be seen by browsing through the proceedings of ICAD, but there have been fewer such tools developed exclusively for sonification of graphs, such as MUSE [35] and the Sonification sandbox [36]. Future work in this area could focus both on systematically testing the utility of the currently available tools and on developing other such tools for use in specific environments.

4. ROLE OF MEMORY AND ATTENTION

Cognitive psychologists have provided myriad information about the effects of sound on memory and about the effects of multiple tasks on attention. From this research, auditory graph investigators have used two principles on the impacts of using sound and vision together for graphed data. One of these principles is that adding another modality (i.e., audition to vision) will result in redundancy in the information, and thus lead to better overall comprehension of graphs. The second principle is that having two modalities will result in divided attention leading to greater cognitive load, and thus to diminished comprehension of graphs. It would be useful for auditory graph researchers to determine in which situations these two contradictory effects manifest themselves. Such information could be used for sonification of data either alone or in conjunction with visual graphs when appropriate.

5. REAL-WORLD APPLICATIONS

There are a number of real-world applications of auditory graphs that have been explored by sonification researchers. For example, auditory graphs have been used as part of assistive technologies for people who are blind or who have other visual impairments [37][38][39][40][41][42]. In general such studies have compared auditory with kinesthetic methods and the combination of the two for providing graphical information for people who cannot use the visual modality. Such studies have reported inconsistent results, which suggests that this is promising area for future research.

A second important area for real-world applications is in education. Young children use sound in a variety of ways to learn material, such as singing the alphabet. Older children and young adults also use sounds as mnemonic devices to learn material; for example, English speakers learning German can use a song as a method for remembering which articles use accusative or dative endings in specific grammatical constructions. Therefore, it would appear that exploring the use of auditory graphs within educational systems could lead to methods that would improve learning for children. Currently, there has only been limited work in this area; for example Upson's work with adolescents using Cartesian graphing with sonification software for mathematics [43][44]. Therefore, this appears to be a promising field of research for those interested in educational issues.

The last area of applied work for sonified data can be found in methods of adding sound to complex datasets produced in industry, business, and the financial world. Recently researchers have used sonification for stock market data [45][46], exploration of high dimensional datasets [47] and for oil and gas exploration [48]. Continued work with these large and complex datasets could provide effective tools for active and ongoing data exploration that is difficult to perform using vision.

6. LONGITUDINAL STUDIES OF LEARNING

It is clear from both previous research on visual graphs presented earlier in this paper as well as from the experience of teachers in pre-college and college education that people need training in graph reading, interpretation, and construction. This suggests two important aspects that researchers working with auditory graphs should take into consideration for their studies. The first issue is that such researchers should be taking into account the knowledge base developed by researchers who investigate visual graphs. This seems to be a prudent step since it can be hypothesized that similar underlying cognitive processes are taking place when comprehending and interpreting both auditory and visual graphs. Results of such studies could be used to guide and provide hypothesizes for auditory graph studies that could either refute or support a general cognitive process for comprehending both types of graphs.

The second issue relates to the basic research designs that auditory graph researchers have used extensively in the past; specifically, one-shot studies. If we know that it takes extensive training to enable people to use visual graphs, it seems reasonable to assume that it also takes a longer time than one exposure to train someone to use auditory graphs. Thus, it may be that using only one-shot studies is not providing relevant data and, in some cases, may even be providing misleading data since the participants do not have sufficient practice to be able to use the auditory versions of graphs effectively. The literature shows only a few examples of learning studies in this area [44]. Recently, research in my lab was completed on a longitudinal study comparing the comprehension of visual and auditory graphs of real data sets that was first outlined as part of a systematic research project at ICAD in 2001 [49]. Preliminary data analysis suggests that practice has direct impact on the ability to comprehend both visual and auditory graphs, and that larger gains in comprehension occur with the auditory versions. These results suggest that using more longitudinal designs should be a serious consideration for auditory graph investigations, in spite of the difficulties inherent and expense in conducting such studies.

7. NEUROPHYSIOLOGICAL RESEARCH

Cognitive neuroscience researchers have shown very limited interest in investigating the physiological substrates responsible for visual graph comprehension, and during a recent search through the relevant literature, there were no studies found that considered auditory graph processing. I recently performed research comparing auditory and visual graphs using Evoked Response Potentials at the University of Louisville with Fonaryova Key that has not yet been submitted for publication. The results suggest that processing visual and auditory graphs together is a more difficult task than processing either alone. This seems to suggest that further research using neurophysiological techniques could help to shed light on the issue of cognitive load both during active processing of visual and auditory graphs in addition to helping address the question of whether adding sound to visual graphs is detrimental or helpful for comprehension.

8. CONCLUSION

It is clear from the proceeding material that work in the area of auditory graph research has made great progression in the recent past. It is also equally evident that now the time is ripe for review, reflection, and planning in order that the field may move constructively forward in a collaborative manner. It is my hope that this paper will be serve as one of the useful implements to spur the discussion.

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