THE INTERACTIVE BEHAVIOR TRIAD AND AUDITORY GRAPHS: SUGGESTIONS FOR AN ORGANIZING FRAMEWORK

S. Camille Peres and Michael D. Byrne

Rice University,
Department of Psychology,
Houston, TX
USA
peres@rice.edu and byrne@rice.edu

ABSTRACT

Auditory graphs are important tools for the display of information for those with visual impairments and in situations with a reduced opportunity for visual displays. The first annual Auditory Graph Symposium provides an important and unique opportunity for auditory graph researchers and designers to come together and discuss the current state of the field, what we would like to see happen over the next five to ten years, and how we plan on accomplishing these goals. This paper presents a possible framework for organizing and informing this research. The Interactive Behavior Triad (IBT) is a framework for examining, and ultimately predicting, human behavior in interactive environments. The IBT identifies the three elements necessary to predict interactive behavior, specifically, embodied cognition, the task, and the environment associated with the performance of the task by the operator (i.e., the person). When all of these elements of the interactive behavior of using auditory are considered and understood, the community of auditory graph researchers and designers will better be able inform the design and utilization of these important displays.

1. INTRODUCTION

The use of sound to display data is not a new phenomenon. For instance, the Geiger counter has been in use since the early 1900's for measuring radiation. Indeed some work has indicated that the Geiger counter's auditory display is more effective for measuring radiation than a visual or combined (visual and auditory) display [1]. However, many designers have not considered the auditory display of information for broader use until recently when powerful yet relatively inexpensive technology has made the development of auditory displays more practical. One type of auditory display—the auditory graph—has received a good deal of attention from engineers, designers, as well as auditory, cognitive, and Human-Computer Interaction researchers. The work done by these individuals has created a body of knowledge that is scientifically and practically important with regard to the development of a mature understanding of auditory graphs. Ultimately, a mature and comprehensive understanding of auditory graphs will inform not only the best practices for design and implementation of auditory graphs but could have important theoretical implications as well.

A mature and comprehensive understanding of any body of knowledge requires not only the full understanding of the issues and details associated with those issues, but also a clear understanding of how the issues relate to and affect each other. If designers know how different issues regarding auditory graphs relate to and affect each other, but do not have sufficient knowledge regarding the issues themselves, their ability to make accurate predictions is compromised. Conversely, if designers have a thorough understanding of the issues but no clear understanding of how the issues relate to each other, then they may be able to very accurately predict behavior in very specific situations, but not be able to make predictions that generalize to new situations.

The position that all aspects of the interactive process of using auditory graphs must be understood is not a novel one and has been mentioned in much of the research on auditory displays and graphs (e.g., [2, 3, 4, 5, 6]). In this paper, we are suggesting a possible framework for organizing these issues associated with auditory graphs. This organizational framework could possibly facilitate the development of the body of work on auditory graphs from a list of issues that need to be addressed to an organized and comprehensive understanding of auditory graphs—both how to design them and when to use them. An understanding of this sort could allow for predictions of how people will performed when utilizing auditory graphs for many different tasks, in many different environments.

Previous research designed to characterize and predict behavior with HCI tasks [7, 8, 9, 10] has outlined a framework for examining, and ultimately predicting, human behavior in interactive environments. This framework is called the "Interactive Behavior Triad" (IBT) as it refers to the three elements necessary to predict interactive behavior (Figure 1): 1) embodied cognition, 2) the task, and 3) the environment associated with the performance of the task by the operator (i.e., the person).

This paper will first present the IBT and then illustrate how the three components relate to auditory graphs. Then we will present how some of the previous research on auditory graphs fits into this triad. We will list some potential benefits of using the IBT to develop an organizational framework for the study and development of auditory graphs. Finally, we propose a possible mechanism for realizing the use of this framework, specifically a framework that will allow for a systematic method of collaborating between and among the auditory graph researchers, designers, and users.

2. THE INTERACTIVE BEHAVIOR TRIAD

Reading and using graphs is essentially an interactive behavior given that successful reasoning based on a graphical representation requires the interaction between the user's cognitive skills, the graphical representation itself, and the task being done by the user. Thus, it stands to reason that a deeper understanding of the relationship between these three elements will facilitate the design of effective graphs. Under the IBT, the graph would be considered part of the environment, the cognitive skills of the user would be part of the embodied cognition, and the task being conducted is clearly placed in the task component of the IBT.

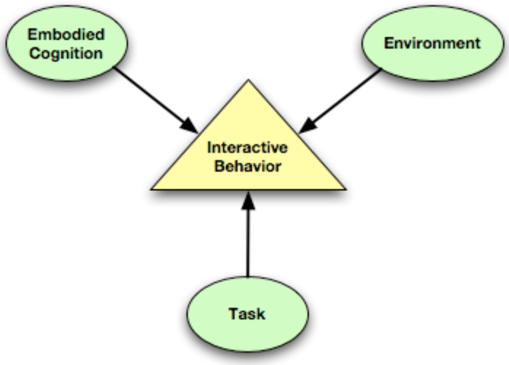

Figure 1. *Interactive Behavior Triad—this figure illustrates how interactive behavior is composed of embodied cognition, the environment, and the task.*

2.1. Interactive Behavior Triad

In the IBT, embodied cognition is considered the perceptual, behavioral-motor, and cognitive properties and limitations of the user. For auditory graphs this could include: the cognitive properties associated with the perception of sounds; the impacts of divided attention on performance; any difference in performance for sighted users versus those with visual impairments, etc. Much of the work done by cognitive psychologists on auditory displays and graphs has addressed these types of issues (for example, [5, 11, 12, 13]).

The task in an interactive behavior is the goal the person is trying to accomplish and the knowledge required to do this task. The type of tasks that auditory graphs have been used for vary greatly from determining the price of a particular stock [14, 15] to analyzing data on weather records [3] to learning mathematical functions [16].

The environment in the IBT consists of not only the situation where the user is performing the task (and all of the affordances and limitations associated with that situation) but also the artifact (or in this case, the graph) itself. All physical environments have different properties and constraints and these the designer must considered these when developing auditory graphs. For instance, when Janata and Childs designed an auditory display for use by stock traders, they took into account the high cognitive demands of that environment [14]. Under the IBT, the environment would include not only the actual auditory environment: noise conditions, etc. but also the history of auditory experiences. For example, someone with a long history of using Geiger counters already has a clear mapping from "tempo" to "amount." With regard to the actual graph, the design of auditory graphs varies as much as the design of visual graphs. Auditory graphs incorporate the different dimensions of sound to represent the data (as in a scatter plot) or summary of the data (for a bar chart). They can also be designed to include context information to assist the user with interpretation of the graph [15, 17].

3. PREVIOUS WORK

This articulation of the three elements of interactive behavior is not novel. Indeed, researchers and designers have known about and addressed these three elements of interactive behavior previously. However, they frequently considered the elements in a pair wise fashion rather than altogether. For instance, psychological research will often utilize tasks that require little support from the environment in order to isolate variables associated with cognition and/or a particular task. While this allows for experimental control, this focus on cognition and task minimizes the role of artifact/environment thus reducing the ability to understand the effects that environment may have on the particular task/cognition interaction.

A good example of an experiment that allowed for the investigation all three elements of the IBT—the task, the environment, and the cognition—was conducted by Peebles and Cheng [18]. This experiment examined participants' performance (speed and accuracy) and eye-tracking behavior with several different tasks using two types of graphs.

Embodied Cognition. Peebles and Cheng used a computational cognitive architecture (ACT-R) and its associated mechanisms to represent human cognition. This includes primitives for things like timing of shifts of visual attention, products of those attentional shifts, and memory mechanisms such as decay over time.

Task. Experimental participants were asked to do a number of tasks, such as "when the value of X is 2, what is the value of Y?" (X and Y were instantiated in various ways throughout the experiment). A cognitive task analysis supported the notion that to make clear predictions, decomposition into subtasks was required. Detailed analyses of the subtasks and their sequence were also conducted.

Environment. The environment here consisted of visual line graphs of two types, functional and parametric. These graphs were deemed "informationally equivalent" (that is, any information one could obtain based on one graph type could also be obtained from the other).

What Peebles and Cheng found was a clear interaction between these constraints. Despite being informationally equivalent, the two graph types did not yield equivalent performance—but it depended on what the task was. Because of factors like working memory limitations (supported by analysis their eye-tracking showing revistations of visual elements during the task), the operations required in some subtasks were more difficult than others, and seemingly small surface-level differences between representational elements resulted in large differences in the cognitive processes required for a specific task, thus yielding substantial differences in performance. Furthermore, many participants performed better with the less-familiar parametric graph type when it was well-matched to the task, supporting the idea that performance is not merely driven by familiarity.

The study by Peebles and Cheng [18] illustrates how performance associated with an interactive behavior (i.e., reading a visual graph) can depend on the cognitive resources necessary to perform the task, the type of task being done, and the type of graph used to perform the task. It follows that the same dependencies exist in the interactive behavior of using auditory graphs. While research on auditory graphs has made great progress in the last decade, it has been primarily limited to the examination of the elements in the IBT in a pair wise fashion [2, 12, 15, 19, 20]. We offer the suggestion that it is through a thorough understanding of the interaction between cognition, the task, and the environment that appropriate uses and designs of auditory graphs can be examined.

In addition to offering insight regarding the appropriate design of auditory graphs, insight gained through an understanding of the interaction between the three elements of the IBT may also inform when auditory graphs could be beneficial over visual graphs. Specifically, there are instances where auditory graphs are necessary because visual ones are not possible (e.g., for individuals with visual impairments, for environments with small displays, etc.). In addition, there are other instances where both visual and auditory displays are feasible but one may be better suited for the task at hand or for a particular environment (e.g., dual task). In the latter situation, if the cognitive requirements associated with a particular task in one environment are different for the same task in a different environment, it is conceivable that for one environment an auditory graph is better while for the other a visual graph would be more appropriate. Furthermore, with a clear understanding of the relationship between cognition, environment, and tasks, a framework could be established which provides designers information regarding the type of display (and best format for the display) for different types of task in different environments. For instance, the framework designed by Hajdukiewicz and Wu [21] could be developed to include auditory displays as well as visual displays. Hajdukiewicz and Wu's framework suggests different visual displays for the representation of time-based information in a refinery monitoring environment. The framework provided suggestions regarding the appropriateness of different types of displays based on the nature of the task and the information needed. For example, when information regarding the current state of the processing system was needed, the framework indicated that a trend plot could provide information but not exact values but a numeric trend plot could give exact information regarding the current state of the system. A framework of this type developed with information regarding the interaction between the elements of the IBT could not only provide important information for designers of displays, but could also provide guidance for researchers with regard to the areas where more information, and thus research, is needed.

4. ORGANIZING FRAMEWORK FOR COLLABORATIONS

This paper provides support for the idea that the auditory graph (and auditory display) community could benefit from considering the issues associated with auditory graphs within the framework of the IBT. We suggest that when addressing problems associated with auditory graphs, researchers and designers should not only examine the three elements within the IBT but may also want to identify collaboration opportunities that facilitate the investigation of all three elements under the IBT. For example, the first author has done research regarding the effects of using dimensions of sound redundantly for the display of auditory box plots. Indeed, this work found benefits in performance when integral dimensions of sounds were used redundantly versus when separable dimensions of sound were used for the same display [12]. Furthermore, this benefit was found in both single and dual task environments. However, the task in this research was an artificial one created for the study. This work would be better able to inform the design of auditory graphs if it were applied to a real task. Through collaboration with someone looking to develop a display for a specific, real world task, the findings regarding the benefits of using integral dimensions of sound redundantly could be most appropriately tested and applied

5. SUMMARY

The Auditory Graph Symposium provides auditory graph designers and researchers a unique opportunity to evaluate the current state of knowledge regarding this important type of display. This paper is presented to offer food for thought regarding how to best organize continuing efforts to develop a thorough understanding of all of the issues associated with the interactive behavior of using auditory graphs.

6. REFERENCES

[1] J. Tzelgov, R. Srebro, A. Henlik, and A. Kushelevsky, "Radiation detection by ear and eye," Human Factors, vol. 20, pp. 87-98, 1987.

[2] T. L. Bonebright, M. A. Nees, T. T. Connerley, and G. R. McCain, "Testing the effectiveness of sonified graphs for education: A programmatic research project," presented at International Conference on Auditory Display, Helsinki, Finland, 2001.

[3] J. H. Flowers, L. E. Whitwer, D. C. Grafel, and C. A. Kotan, "Sonification of daily weather records: Issues of perception, attention and memory in design choices," presented at International Conference on Auditory Display, Espoo, Finland, 2001.

[4] G. Kramer, "An introduction to auditory displays," in Auditory display: Sonification, audification and auditory interfaces. Proceedings of the first international conference on auditory displays 1992, G. Kramer, Ed. Reading, MA: Addison-Wesley, 1994, pp. 1-77.

[5] B. N. Walker, "Magnitude estimation of conceptual data dimensions for use in sonification," Journal of Experimental Psychology: Applied, vol. 8, pp. 211-221, 2002.

[6] R. Walker, "The effects of culture, environment, age, and musical training on choices of visual metaphors for sound," Perception & Psychophysics, vol. 42, pp. 491-502, 1987.

[7] M. D. Byrne, "ACT-R/PM and menu selection: Applying a cognitive architecture to HCI," International Journal of Human-Computer Studies, vol. 55, pp. 41-84, 2001.

[8] M. D. Byrne, A. Kirlik, and C. S. Fick, "Kilograms matter: Rational analysis, ecological rationality, and closed-loop modeling of interactive cognitive systems," in Adaptive perspectives on human-technology interaction: Methods, models, and measures, A. Kirlik, Ed. New York: Oxford University Press, in press.

[9] W. D. Gray, "The nature and processing of errors in interactive behavior," Cognitive Science, vol. 24, pp. 205-248, 2000.

[10] W. D. Gray and E. M. Altman, "Cognitive modeling and human-computer interaction," in International encyclopedia of ergonomics and human factors, W. Karwooski, Ed. New York: Taylor & Francis, Ltd., 1999.

[11] J. G. Neuhoff, G. Kramer, and J. Wayand, "Sonification and the interaction of perceptual dimensions: Can the data get lost in the map?" presented at International Conference on Auditory Displays, Georgia Institute of Technology, Atlanta, GA, 2000.

[12] S. C. Peres and D. Lane, "Auditory Graphs: The effects of redundant dimensions and divided attention," presented at International Conference on Auditory Displays, Limerick, Ireland, in press.

[13] B. Walker and A. Ehrenstein, "Congruency effects with dynamic auditory stimuli: Design applications," presented at International Conference on Auditory Displays, Palo Alto, CA, 1997.

[14] P. Janata and E. Childs, "Marketbuzz: Sonification of real-time financial data," presented at International Conference on Auditory Displays, Sydney, Australia, 2004.

[15] D. R. Smith and B. N. Walker, "Tick-marks, axes, and labels: The effects of adding context to auditory graphs," presented at International Conference on Auditory Display, Kyoto, Japan, 2002.

[16] A. D. N. Edwards and R. D. Stevens, "Mathematical representations: Graphs, curves, and formulas," presented at INSERM Colloquium, Non-Visual Human Computer Interaction, London, England, 1993.

[17] R. Bargar, "Pattern and reference in auditory display," in Auditory display: Sonification, audification and auditory interfaces. Proceedings of the first international conference on auditory displays 1992, G. Kramer, Ed. Reading, MA: Addison-Wesley, 1994, pp. 151-166.

[18] D. Peebles and P. C.-H. Cheng, "Modeling the effect of task and graphical representation on response latency in a graph reading task," Human Factors, vol. 45, pp. 28-45, 2003.

[19] J. H. Flowers, D. C. Buhman, and K. D. Turnage, "Cross-modal equivalence of visual and auditory scatterplots for exploring bivariate data samples," Human Factors, vol. 39, pp. 341-351, 1997.

[20] J. H. Flowers and T. A. Hauer, "Musical versus visual graphs: Cross-modal equivalence in perception of time series data," Human Factors, vol. 37, pp. 553-569, 1995.

[21] J. Hajdukiewicz and P. Wu, "Beyond trends: A framework for mapping time-based requirements and display formats for process operations," presented at Human Factors and Ergonomics Society 48th Annual Meeting, New Orleans, LA USA, 2004.