PSYCHOPHYSICAL SCALING OF SONIFICATION MAPPINGS WITH BLIND AND VISUALLY IMPAIRED LISTENERS

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ABSTRACT

We used magnitude estimation to determine preferred data-to-display mappings, polarities, and psychophysical scaling functions relating perceptual and conceptual data values to underlying acoustic parameters for blind and visually impaired listeners. We compare the resulting scaling functions to previous findings with sighted participants [1]. The findings have implications for the design of future sonifications for both blind and sighted users.

1. INTRODUCTION

Determining patterns in data is a primary activity for scientists and students. These data sets are increasingly large and complex, making successful scientific exploration an ever-increasing challenge. There are many software tools available for exploring and analyzing data, however they are almost exclusively visual in nature. Such programs do not provide a means for blind and visually impaired students and researchers to participate fully in the scientific endeavor.

Sonification, the use of non-speech audio to display data, can provide crucial data analysis tools for *all* researchers, not only those who are unable to use visual plots and graphs (see [2]). However, to ensure that sonification is useful and effective, the auditory display designer must consider the perceptual and cognitive expectancies of the end user—the listener—and not make design decisions based solely on what sounds "good" or "intuitive" to the designer [1][3].

Walker [1] points out that to create an effective sonification the designer must determine the optimal display dimension (i.e., sound attribute) to represent the data dimension; the polarity of that mapping; and the scaling of the mapping. Walker used the psychophysical paradigm of magnitude estimation (see also [4]) with both perceptual and conceptual judgments to answer all three of these questions for several data and display mappings. Walker found that the preferred mapping, polarity, and scaling function all depended on both the data and display dimensions in use. That is, it matters not only what sounds are used, but also what data those sounds are meant to represent. Temperature should be presented differently from, for example, pressure or velocity.

All of the results in this line of research ([1][3][5]) have been obtained with sighted college students. It is important to continue to replicate and expand the findings in that population. However it is also critical to determine the preferences of other populations, particularly blind and visually impaired listeners. It is not clear how the mappings, polarities, and scaling functions determined with visually impaired experimental participants will would compare with data from sighted students.

If the results are similar, then development of sonification software may require only one set of synthesis algorithms. However, if different results arise, then auditory display designers and software developers will certainly need to take the broader findings into account. Regardless, the specific needs of visually impaired users must be considered when developing any sonification software.

2. METHOD

This study replicated the procedure used by Walker [1, Experiment 3], but with blind and visually impaired participants. Details of the stimuli and experimental procedure are available in [1]. An abridged description is provide here, with departures from the original specified.

[Note to reviewers: This experiment is currently underway. Fictitious results are reported here. We will report full details of the actual findings at ICAD.]

2.1. Participants

Forty blind and visually impaired youths from various Texas high schools and universities participated (xx males, yy females, mean age, zz years). Several of the participants are students at the Texas School for the Blind and Visually Impaired in Austin.

2.2. Stimuli

We employed the two sets of sound stimuli used by Walker [1, Experiment 3]. Full synthesis details are provided in that report. The 10 sounds in the Frequency Set were sine tones each 1 s in duration, synthesized at frequencies of 100, 200, 300, 400, 800, 1000, 1400, 1800, 2400, and 3200 Hz. The 10 stimuli in the Tempo Set were each patterns of one beat of sound followed by one-half beat of silence. They were synthesized with a tone frequency of 1000 Hz and were repeated at tempos of 45, 60, 105, 150, 210, 270, 420, 500, 550, and 600 beats per minute (bpm). All sounds were equated for apparent loudness.

Participants made judgments about the perceived pitch and tempo of the sounds, as well as conceptual estimates of the temperature, pressure, velocity, size, and number of dollars that the sounds would represent.

2.3. Procedure

In one blocks of trials, participants responded to the sounds from the Frequency Set, one stimulus at a time. In a separate block of trials, participants responded to the Tempo Set. The 10 sounds from each of the stimulus sets were presented twice each in random order for a total of 20 trials per block. One of the blocks involved simple perceptual judgments of the stimuli, whereas the other block involved conceptual estimates of one of the five data values. The order of the blocks was counterbalanced.

On each trial, one of the sounds was presented via headphones, and the participant responded with a number that he or she felt estimated the value of the perceptual or conceptual data dimension in use during that block. For example, the participant might listen to sounds of different frequencies, and indicate what "temperature" each sound represented. A sighted assistant helped the participant to play the sounds and enter the responses.

3. RESULTS

We sorted the data by display dimension and data dimension. Then, within each data-to-display pairing, we calculated the geometric mean of all responses for each stimulus. For each mapping, we plotted the estimated data values against the actual tempos or frequencies of the sounds, on log-log axes. A best-fit line was calculated for each plot, with the slope of the line indicating how much change in, say, temperature was estimated for a given change in the actual frequency of the stimuli.

Figure 1 contains the resulting psychophysical scaling plot for the perceptual estimations of pitch; that is, the amount that the perceived pitch changed as a function of the actual frequency change. This plot is representative of the results obtained for all of the data-to-display mappings. Figure 2 presents the function for estimated size versus sound frequency. Table 1 summarizes the slopes of all of the scaling functions determined in this experiment. Note that a negative slope indicates that an increase in the display dimension (e.g., an increase in frequency) represents a decrease in the data dimension (e.g., a decrease in size).

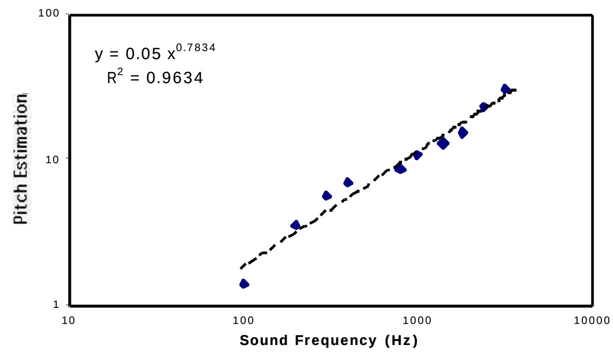

Figure 1. *Pitch estimation versus sound frequency.*

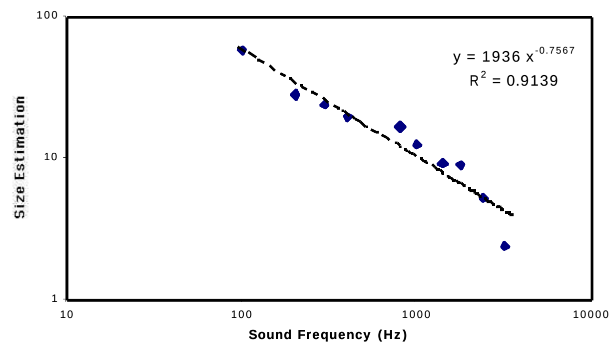

Figure 2. *Size estimation versus sound frequency.*

4. DISCUSSION

4.1. Perceptual Estimations

All participants responded with a positive polarity for both of the perceptual estimations, pitch and tempo. The slopes of resulting scaling functions, 0.78 and 0.95 respectively, are nearly exactly the same as the corresponding slopes obtained with sighted participants [1]. This indicates that the experimental method works, and more importantly that the visually impaired listeners' perceptions of the sound changes is similar to those of sighted listeners.

Table 1. *Summary of psychophysical scaling slopes with visually impaired listeners*

Display dimension	Slope of regression line						
	Temperature	Pressure	Velocity	Size	Dollars	Pitch	Tempo
Frequency							
$+^{ve}$ Polarity	**[Data TBD...]**						
$-^{ve}$ Polarity							
Tempo							
$+^{ve}$ Polarity							
$-^{ve}$ Polarity							

Note: The slope for the most popular polarity for each data-to-display pair is shown in bold face.

4.2. Conceptual Estimations

As listed in Table 1, some of the slopes for the conceptual data dimensions were unanimous in favor of one polarity. This was not always the positive polarity, as evidenced by the size versus frequency plot in Figure 2. Most of the mappings, however, resulted in non-unanimous polarities. The approximate levels of unanimity on a mapping-by-mapping basis also differed from [1].

Further, the slope values were different for the various data-to-display mappings, as was the case with sighted participants in [1]. The values of the slopes obtained in the present experiment were in some cases very close to those from [1], but in other cases the values are strikingly different.

The finding of different levels of unanimity and different scaling functions for some of the mappings indicates that visually impaired listeners may have different mental models of the underlying data structures, which lead to different estimates of what data values a given sound represents.

4.3. General Conclusions

Although these results will need to be replicated and extended, the implication is that visually impaired listeners may hear the sounds in a way that is similar to sighted listeners, but they conceive of the represented data in different ways. Auditory display designers and sonification systems will need to further develop appropriate scaling models for blind and visually impaired users, and include the appropriate mappings, polarities, and scaling functions in order to capture and capitalize on the perceptual and conceptual expectancies of that particular end user population. Simply designing for sighted users will presumably not yield the highest level of comprehension, and therefore effectiveness, of sonifications when used by researchers and students with visual disabilities.

5. REFERENCES

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