INDIVIDUAL DIFFERENCES AND THE FIELD OF AUDITORY DISPLAY: PAST RESEARCH, A PRESENT STUDY, AND AN AGENDA FOR THE FUTURE

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ABSTRACT

There has been some interest in the study of individual differences in the field of auditory displays, but we argue that there is a much greater potential than has been realized, to date. Relevant types of individual differences that may be applicable to interpreting auditory information include perceptual abilities, cognitive abilities, musical abilities, and learning styles. There are many measures of these individual differences available; however, they have not been thoroughly utilized in the auditory display arena. We discuss several types of individual differences relevant to auditory displays. We then present some examples of past research, along with the results of a current investigation of individual differences in auditory displays. Finally, we propose an agenda as to what research and tests should be used to further study this area.

[Keywords: Individual Differences, Auditory Display, Cognitive, Musical Abilities]

1. INTRODUCTION

The field of individual differences involves the study of how and why there are differences between individuals, and how such differences can impact performance on some task. Individual differences have been studied in many fields of science, particularly psychology. There has been some interest in the study of individual differences in the field of auditory displays, but we argue that there is a much greater potential than has been realized, to date. More and different tests, for a broader range of differences, may lead to an expanded understanding of differences between listeners, and thereby lead to more effective auditory displays. Although no formal guidelines have been made to specify when the auditory display should be fitted to each person, we can see this type of tailoring potentially being used in a classroom setting or by people with visually impairments. Hopefully, this line of research will lead to such guidelines being developed.

As the field of auditory display continues to mature, our understanding of the processes involved in using sonifications and auditory graphs will naturally increase. This is already leading to the presentation of models and schemas that tie together the user, the display, and the task [1]. Researchers are exploring each of these areas; we concentrate here on a discussion of the "user" element, and in particular, we make the case that it is important not to view all users as if they were equal to some mythical modal or average user. Quite simply, people are different, and they are different in ways that may very well matter for auditory display use and interpretation.

This paper starts with a discussion of several types of individual differences that are important in the interpretation and design of auditory displays. Along with this discussion, a list has been included of possible tests to measure these differences among people. We then present some examples of past research, along with the results of a current investigation of individual differences in auditory displays. Finally, we propose an agenda as to what research and tests should be used to further study this area. Hopefully, researchers will unite to tackle these questions in a collaborative effort.

2. TYPES OF INDIVIDUAL DIFFERENCES

There are many types of individual differences that are likely involved in the use and interpretation of auditory displays, and as a result should be studied somewhat more than we have seen. Individuals differ in many ways, and even categorizing the differences is not straightforward. However, for our purposes the relevant ones can be categorized as perceptual abilities, cognitive abilities, musical abilities, and learning styles. Along with these areas come numerous tests to measure those individual differences.

2.1. Perceptual Abilities

Before a listener can even attempt to interpret the information conveyed by an auditory display, the sounds must be heard and differentiated. There is a great range of auditory perception abilities, along many dimensions such as absolute thresholds, frequency perception, temporal acuity, and change detection. The field of audiometry has developed easily-administered and sophisticated measures of hearing ability, which can provide important basic information about listeners, much as tests of visual acuity, field of view, and color perception can predict performance with visual displays. Beyond basic auditory perception, there are several tests of how listeners begin to interpret acoustic signals. Some examples include the *Test of*

Auditory Reasoning and Processing Skills (TARPS), which is a test of perception of auditory material for 5 to 14 year olds, and the *Test of Auditory Processing Skills Third Edition* (TAPS-3), which is a test of auditory processing for 4 to 18 years olds. These kinds of tests may prove very useful in understanding how auditory displays are perceived, and initially parsed.

2.2. Cognitive Abilities

Auditory displays require interpreting sounds, which depends on comparisons, trend analyses, interpolation, extrapolation, and so on. It is clear that cognitive abilities should play a role in auditory display use, and differences in such abilities are important to consider. Memory, spatial reasoning, and overall intelligence are likely predictors of auditory display performance, and there are many well-studied tests for these cognitive components. For example, working memory capacity (WMC) is often assessed using the *N-back Test* and the *Operation Span (Ospan) Test*. Spatial reasoning is often examined via Raven's Progressive Matrices. General intelligence has been assessed over the years with a range of measures, but some that are particularly suitable for our field may include the *Slosson Intelligence Test Revised*, which can be used with visually impaired and blind individuals, the *Structure of Intellect Learning Abilities Test*, and the *Shipley Institute of Living Scale*. In addition, tests specific to attention may also provide insight to auditory display usage. One example is the *Test of Everyday Attention*. These are just some of the many tests of cognitive abilities that could be useful in the study of individual differences with respect to auditory displays.

2.3. Musical Abilities

It seems patently obvious that people who are trained to listen to sounds in the ways that musicians are, should be far more effective when it comes to extracting the information contained within an auditory graph or sonification. There are many ways one can measure musical ability, and its related concept, musical experience. The number of years of music lessons, the number of years playing an instrument, or the number of years performing can all serve as surrogates to actual musical ability. There are more direct ways to measure ability, however, such as the *Seashore Measures of Musical Talent* and the *Musical Aptitude Profile*.

2.4. Learning Styles

Some people prefer to learn materials visually, whereas other people prefer to hear information aurally. This well-known difference in learning styles may very well have an impact on how effectively a person extracts information from an auditory display, as compared to a visual or multimodal display. There are some tests to measure learning styles, such as the *Learning Styles Inventory*, the *Learning Efficiency Test II*, and the *Rey Auditory Verbal Learning Test (RAVLT)*. Presenting information in the most effective modality (or modalities) for a specific person will likely lead to better information retrieval. A classroom setting where students comprehend the material at different rates is a good example of how the presentation of information could be designed for the specific learner.

3. PAST INDIVIDUAL DIFFERENCES RESEARCH

Despite the abundance of tests to study relevant abilities (perceptual, cognitive, musical, learning styles, and more), there has been relatively little research on individual differences with respect to listening to and interpreting sonifications and auditory displays. This is not to say, however, that there has been *no* such research. There has. Some of it has been explicit and intentional, while some has been more focused on other issues, and the individual differences knowledge has resulted as a secondary product. In some cases the researchers frame their research in terms of (and in the terminology of) individual differences, and sometimes the intent is there, but a different framing and vocabulary can be seen. Regardless, all of these lead us closer to understanding how different people interact differently with an auditory display.

Although not explicitly framed as a study of individual differences, research with an auditory magnitude estimation task has demonstrated that important differences in the interpretation of auditory information arise within and between groups of listeners [2-5]. Walker [4] found individual differences in college students in the polarities of responses to data-to-sound mappings. The polarity of a mapping describes how changes in a display dimension signify changes in the data dimension. For example, if tempo increases to represent increasing urgency in a given data set, the mapping has a positive polarity. If the tempo *decreases* with increasing urgency, then the respective mapping would be classified as having a negative polarity. Walker [4] found that in some cases a majority of the listeners clearly preferred either a positive or a negative polarity, whereas in other cases there was a split between positive and negative polarities being preferred for a given data-to-display mapping.

Walker and Mauney [2] and Walker and Lane [3] found differences between groups of visually impaired and sighted listeners. Those two studies indicate that in some situations visually impaired and sighted listeners respond with similar polarities of data-to-display mappings, but in other cases different polarities result. For example, normal-sighted individuals preferred a positive polarity when mapping frequency to the data variable "number of dollars", whereas visually impaired individuals preferred a negative polarity. Even within what may, on the surface, seem to be a homogeneous group of people (e.g., sighted persons or visually impaired persons), there can be notable differences between individuals of those groups. These differences demonstrate the importance of further inquiry into the topic of individual differences relating to concepts and mental models.

Neuhoff, Knight, and Wayand [6] found differences in sighted listeners' perceptual and conceptual responses to pitch change. Neuhoff et al. did not specifically discuss individual differences in their study, but that study clearly did investigate individual differences in auditory perception. That study is one of the very few (a surprising fact, by the way) that indicates that listeners with more musical experience scale frequency change differently from listeners with no musical experience. Neuhoff et al. [6] also found that greater musical expertise reduced the amount of errors in judging/labeling the direction of the pitch change.

These findings of a few select types of individual differences in interpreting auditory information have not been consistent nor replicated. Walker and Mauney [7] looked at a wider variety of individual differences and used a more systematic approach to their investigation. The researchers focused specifically on cognitive abilities, musical experience, and a variety of demographics (age, gender, handedness) in their study of individual differences in the auditory magnitude estimation task mentioned previously. They used exploratory statistics and found some support for cognitive abilities affecting the interpretation of auditory displays. Listeners with better scores on working memory capacity (WMC) and spatial reasoning measures performed more consistently (had higher R^2 values) on the magnitude estimation task than those listeners who had lowers scores of WMC and spatial reasoning. However, the slope of the data-to-display mappings did not seem to be affected by cognitive abilities, musical experience, or demographic variables [7]. The literature discussed to this point does not yield an entirely consistent picture, but it does provide a starting point for a more thorough, systematic study of individual differences in auditory displays interpretation.

The literature mentioned above indicates that individual differences are sometimes related to the interpretation of auditory displays. However, in order to fully understand this relationship, we must first investigate individual differences between and within groups of listeners. We report, now, on some of our current research being done to investigate some perceptual individual differences (i.e., frequency and tempo discrimination), cognitive individual differences (i.e., WMC and spatial reasoning), and that is beginning to explore some aspects of training (i.e., musical experience).

4. CURRENT RESEARCH

The ultimate goal of this line of research is to understand how different abilities relate to performance on an applied auditory display task, such as stock market trend analysis. However, before such an applied task can be examined, there remains considerable work to be done in understanding the individual differences themselves, and how they relate to each other. For example, there has been some recent evidence that working memory capacity (WMC) and pitch perception are correlated [5]. This suggests that other perceptual skills like tempo discrimination might be correlated with WMC, or possibly with other cognitive abilities.

Since frequency discrimination, tempo discrimination, working memory, and spatial reasoning are fundamental skills for interpreting auditory displays, as a first step in this arena the current research investigates the question of whether or not cognitive abilities and musical experience predict frequency and tempo discrimination in individuals. Fifty participants have so far been included in the study, including undergraduate students from the Georgia Institute of Technology and adults from the Atlanta, Georgia community. These participants took part in two sessions of experiments, one that comprised the auditory discrimination task and the other that comprised the cognitive ability tasks. In the cognitive ability session, participants completed the Operation Span (Ospan) task as a measure of WMC and the Raven's Progressive Matrices task as a measure of spatial reasoning. In the auditory discrimination session, participants performed a tempo and a frequency discrimination task. The task included a two-interval forced choice paradigm, in which listeners heard two sounds separated by a brief silence, and were asked to make judgments about differences in the stimuli. The result of this method was a measure of difference thresholds, or the smallest difference in frequency or tempo that the listener could reliably detect. The tempo discrimination task used standard tempo speeds of 150 ms inter-click interval (ICI), 250 ms ICI, and 350 ms ICI and the frequency discrimination task used standard tones of 250 Hz, 840 Hz, and 1600 Hz. Demographics on age, gender, handedness, years of playing a musical instrument, and years of formal musical training were also collected.

A correlational analysis was performed between all independent variables (difference thresholds at 250 Hz, 840 Hz, 1600 Hz, 150 ms, 250 ms, and 350 ms; Ospan; Raven's; age; gender; handedness; years of playing a musical instrument; and years of formal musical experience). Paired-samples t-tests on the Weber fractions of the six threshold means were also performed to determine if there were any significant differences between the thresholds at the difference frequencies or between the thresholds at the different tempos. Finally, multiple hierarchical regressions were performed on each of the six threshold measures in order to identify significant predictors of frequency and tempo discrimination. The paired samples t-tests showed a significant difference between frequency difference thresholds at 250 Hz and 840 Hz and between thresholds at 250 Hz and 1600 Hz, which is a violation of Weber's Law. However, this violation of Weber's Law may be explained by the small sample size used in the study. The t-tests also showed a significant difference between the tempo threshold differences at 150 ms and 250 ms, and between the means at 250 ms and 350 ms.

The preliminary results of the correlations and regressions show that WMC and spatial reasoning are correlated, which was seen in the significant positive correlation between Ospan and Raven's. The results also showed that WMC did not predict performance on frequency discrimination; no significant relationship was found between Ospan and any of the frequency thresholds in either analysis. One explanation could be that the current study has some range restriction problems with Ospan scores, namely, the sample had more high spans than mid and low spans. This range restriction may be attributed to having more Georgia Tech students than Atlanta community participants. The results of the study showed that, in one situation, WMC predicts performance on tempo discrimination; there was only a significant relationship between Ospan and 350 ms. This finding may be due to differences in the possible strategies used by the participants in the slower versus faster tempo discrimination tasks. The results indicate that WMC may play a bigger role in discriminating between slower tempos.

The results also indicate that spatial reasoning ability sometimes predicts performance on frequency discrimination; there was only a significant relationship between Raven's and frequency discrimination thresholds at 1600 Hz. Although not found to be a significant predictor in the regression analysis, there was a significant correlation between Raven's and frequency thresholds at 250 Hz and 1600 Hz. One possible explanation for the general lack of significant relationships between Raven's and frequency discrimination, is that only one of the three possible sets of Raven's problems was used in the current study. This was done for efficiency, however a possible implication of using the smaller response set is that there is also a range restriction in Raven's scores with the current study. The results also show that spatial reasoning ability does not seem to predict performance on tempo discrimination. There were no significant relationships found between Raven's and any of the tempo thresholds in either analysis.

The results indicate that musical experience predicts performance on frequency discrimination only in certain cases; only a significant correlation was found between years of musical training and frequency discrimination at 1600 Hz. With respect to the predictions for musical experience, the literature has mixed findings for the relationship between musical experience and auditory discrimination tasks. This study showed that there was really no significant predictive relationship between musical experience and frequency discrimination, although the one correlation was found between discrimination at 1600 Hz and years of musical training. The general lack of this relationship may be in part related to the very simple questions asked about musical experience, which may not be getting at the essence of the role musical background plays in frequency discrimination. The results also show that musical experience does not predict performance on tempo discrimination; no significant relationships existed between years playing a musical instrument or years of musical training with any of the tempo thresholds. As with the hypothesis of musical experience predicting frequency discrimination, there were mixed findings in the literature regarding the relationship between musical experience and tempo discrimination. Again, the very simple questions asked about musical experience may not be getting at the essence of the role musical background plays in tempo discrimination.

According to the results of the present study, out of the various demographic variables (gender, age, handedness), only gender seemed to have any predictive ability on performance of tempo and frequency discrimination. Gender had a significant beta weight for tempo discrimination at 250 ms and a significant correlation also existed between these two variables, meaning that females seem to have better difference thresholds at 250 ms intervals.

Although most of the predictions held at the beginning of this study have not been confirmed by the regression analyses, the many significant correlations that were found show that the hypothesized relationships may still exist. Due to the relatively small sample size and various range restrictions in certain variables, these relationships, in general, were not found to be significant but could still be in play. These issues are typical of individual differences research for auditory displays—limited sample sizes and range restrictions make it difficult to come to clear conclusions about possible effects. More participants are currently being tested to increase the sample size of the present investigation, especially aiming to increase the number of community participants. Hopefully, this increase in statistical power will lead to stronger and more conclusive findings about individual differences in auditory perception.

5. FUTURE RESEARCH AGENDA

There seems to be some research done in the field of individual differences in the broader area of auditory perception, specifically in the areas of cognitive abilities, perceptual abilities, and musical abilities. However, as mentioned in the beginning, there are many appropriate tests available that have yet to be utilized in the specific area of auditory displays and sonifications. For example, the various tests of intelligence and attention have yet to be researched and some of the perceptual abilities have only been self-report instead of measured with clinical tests (e.g., hearing and vision). In the research to date, results about the role of musical abilities in interpreting auditory information have not been consistent. These inconsistent findings may arise because musical ability is usually measured by basic questions about musical experience and training. We feel that research in this area may really benefit from the use of a more comprehensive and applied test of musical abilities, such as the *Seashore Measures of Musical Talent* or the *Musical Aptitude Profile*. These tests are established and widely used tests of musical abilities and include questions as well as performance measures of musical talent. Unfortunately, these measures may trade off predictive power with ease of implementation, which is a main reason that collaboration will be required as this line of research moves forward. That is, it will simply take longer than in the past for one person to collect data if longer tests are employed, so teams of researchers will need to chare in data collection efforts.

One area that has yet to be researched is the area of learning styles. Although some research has been done in the area of training people to use auditory displays and auditory graphs[1, 8-10] research has not been done specifically on how people prefer to learn (e.g., visual, auditory (non-speech), verbal, haptic, or tactile). Studying about individual differences in learning styles could help in the design of training systems for using auditory graphs or other combinations of graphing systems. As mentioned in the beginning of this paper, there are normalized tests of learning styles that could, and indeed should, be used in future research.

For those researchers who have started investigating individual differences, we recommend continuing and extending research projects to include more tests, different user populations, and larger sample sizes, as well as more applied uses of auditory displays. There is so much basic and applied research needed in these areas that one group of scientists cannot do it all, so collaboration amongst our community and other communities is essential to the advancement of auditory displays, sonifications, and auditory graphs.

It is likely that the best way forward will be the establishment of collaborations and consortia, to study individual differences as applied to auditory displays. Such collaborators will generally use more normalized and common tests of various abilities, such as the tests listed in the beginning of this paper. We especially think it is necessary to investigate those areas of individual differences that have yet to be explored with interpreting auditory information (e.g., attention, intelligence, and learning styles).

As gaps in our data sets are filled, we will be better and better able to refine models of auditory display interpretation, and correspondingly make more effective and more acceptable displays using sound, for all potential users.

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7. REFERENCES

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