INTEGRATING SONIFICATION INTO A LESSON ON JOINT AND COMBINED VARIATION

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Abstract

This project assessed the efficacy and feasibility of a novel teaching method for science and math education based on sonification: generating audio to represent data. Sonification has been used in professional fields but not in K-12 education. Two lessons on joint and combined variation intended for typical middle or high school students were developed. One incorporated a sonification of a sample relationship involving parameter mapping with fundamental frequency, the most easily accessible sonification method. Two forms were used for each lesson, including a background survey, a Visual-Auditory-Kinesthetic learning styles survey, a pre-test, and a post-test. Seventh graders without exposure to the concepts and high schoolers were tested in a single blinded study. Among seventh graders who took the lesson with sonification (n=9), the average improvement ± std. dev. was 50±47%. Among students in the control group (n=9), average improvement was 6±34%. Among only students who were auditory learners, average improvement differed by 63%. The findings imply that sonification may be useful, especially in lessons targeting auditory learners, and further work on the subject is warranted.

Acknowledgements

I would like to thank all the students at Mass Academy who participated in my study for the useful data and feedback they provided. I would also like to thank my wonderful teachers Ms. Curran and Mr. Barnes and my STEM advisor Mr. Regele for their instruction in the process of investigative science and technical writing. Finally, I would like to thank David Peters and the staff at AMSA who helped me test and gather data, and also the seventh graders who participated in my study.

Table of Contents

Literature Review

Introduction

This Literature Review will discuss certain aspects from the field of sonification, education, and learning. The domain of sonification addresses the topic of representing data with sound. Audio representations are a good way of presenting multi-variate data intuitively, and may be especially effective for auditory learners, who learn best through the sounds they hear. Joint and combined variation is the mathematical subject concerned with the relationships between three or more variables that each vary directly or inversely with each other. Though sonification is an established field of study, the applications to education have not been thoroughly explored.

Sonification

Simply put, sonification is the process of representing data using sound. The field of sonification is quite broad, but most uses of sonification involve interpreting data [1]. Sonification is often used to provide audio feedback in cases when alternatives or enhancements to visual feedback are desired or can be more helpful [1]. For example, if one wishes to observe the strength of the vibrations of a certain material, it may be awkward to portray vibrations with visuals but natural to represent them with sound. In the following section, various techniques from existing literature are presented to provide the reader with a background to the field, followed by an overview of the interpretability and relevance of sonification, and a brief analysis of the sonification programs Cheddar, Sonifeye, and Sonification Sandbox.

Techniques

There are three main techniques for sonification: audification, parameter mapping, and physical modeling synthesis [1]. Audification involves directly mapping a data stream into pressure versus time graphs, which results in pressure waves that humans interpret as sound.

Audification is the simplest sonification technique, and sonifications generated from audification are often hard to understand without experience. Parameter mapping is more complex and involves the translating of certain data to parameters that regulate characteristics of sound, also called auditory dimensions, such as pitch (fundamental frequency), volume, duration of notes, and time. Parameter mapping can be effective and comprehensible without much prior experience. Because there are many auditory dimensions which can be numerically adjusted, parameter mapping is good for sonifying multivariate data as an alternative to presenting 3 or more data series on one graph. Physical modeling synthesis, also called model-based sonification, attempts to control properties of sound that are associated with physical properties, often directly moderating timbre. Timbre is the aspect of sound that differentiates different vowel sounds or different instruments, and is related to the shape of a sound wave. For example, a model-based sonification might include audio that sounds like water dripping into a cup with varying amounts of liquid inside to represent the volume of a sample over time. Model-based sonifications are generally the most intuitive and comprehensible. However, the physical properties associated with a sound, such as how full a cup sounds, may not change regularly as the individual properties of sound like volume are altered, so complex data techniques are required for physical modeling synthesis. [1]

Stereo surround sound systems can mimic the effect of sound coming from different directions. Spatial sonification uses perceived direction and volume to map physical position in data to the perceived location of sound in space [2]. The context or richness provided by spatial sonification can help listeners intuitively parse more complex, multidimensional data. [2]. Stereo can also be used to differentiate between two data sets by playing one data set to one ear and another data set to the other [4].

For certain purposes, real-time interaction with data is desired, which can make interactive real-time sonification useful. Real-time sonification also allows increased familiarity with sonification, as changes to data can be associated automatically with changes in audio feedback [2]. However, regular sonification techniques often take too long for real-time sonification due to the amount of data processing required, so interactive sonification systems must be optimized for rapid performance [2].

Minimizing alarm fatigue is also a focus of many more recent sonification programs. One of the main reasons sonification is used for certain augmented reality systems is to improve user concentration by alleviating clutter from visuals [3]. However, if sonifications are irritating or too obtrusive, listening to them for long periods of time can cause alarm fatigue and thus be counterproductive in increasing long-term productivity. One of the common problems that can make sonifications excessively irritating or obtrusive is high volume, or more often sharp or pointed sounds resulting from irritating timbre. [3]

Relevance

Sonification is used in the domain of science for interpreting data and in the arts for composition. In art, work focuses on aestheticism, and audio is often post-processed to sound pleasing [2]. In scientific fields, sonification is used as a tool to interpret data, so accuracy is highly valued. Though aestheticism is not as often prioritized, it can help reduce strain, which allows for prolonged meaningful use of sonification as a way to interpret data [2].

Sonification is frequently used in augmented reality systems as a way of providing audio feedback [3]. Visuals can become cluttered, which often reduces the effectiveness of presenting information visually, as there is a limit to how much data the eye can focus on at once [3]. Offloading some of the visual feedback to an audio format can alleviate strain and allow for the user of an augmented reality system to quickly interpret profuse data by processing a combination of audio and visual feedback [3]. In addition, certain data are easier to interpret as sound. For example, the force with which an object is struck can be mapped to volume, and this might be more intuitive and easier to interpret than the length of a vector arrow.

Interpretability

Sonification has been used by Alonso-Arevalo et al. to provide audio feedback on curve shape and curvature [5]. This research was done in the context of the SATIN project: developing an augmented reality system that allows one to explore and interact with objects in 3-dimensional space similarly to how one explores objects on a 2-dimensional screen with CAD software. Providing feedback on curvature and curve shape is important because they influence how light reflects off the surface of an object, and thus impact aesthetics. The study found that sonification allowed users to analyze curve shape and curvature, as participants successfully identified points of maximum and minimum curvature and points of inflection using sonified audio feedback. The study also employed a kinetic module which post-processed sound to make it more natural and intuitive, but the study did not find significant improvement through use of the kinetic module, implying that physical modeling synthesis will not always reliably improve user experience. The study also suggested that fundamental frequency most effectively provided information to users when analyzing sonifications. [5]

Complex sonification involving multiple properties of sound is often difficult to understand when first heard, and there is a learning curve when using sonification [1]. However, Bonebright et al. found that sonified graphs which mapped two dimensional data to time and fundamental frequency could be matched to their visual counterparts with fair accuracy by students with no background in sonification [4]. In addition, multivariate graphs which mapped two data sets to the pitches of two different instruments were also paired by students to visual graphs with fair accuracy, though with less accuracy than bivariate graphs [4].

Sonification Programs

There are many programs currently available for sonifying data, including Sonification Sandbox, Sonifeye, and Cheddar. Sonifeye is a sonification program that produces audio feedback in the form of sonification for the use of multisensory augmented reality which allegedly requires minimal training to comprehend and apply [3]. The researchers who developed Sonifeye avoided constant feedback and only played sounds based on significant changes so that users would stay alert to feedback instead of growing accustomed to it, thus reducing alarm fatigue. For high precision tasks like holding a needle at a certain angle, users care more about the slight variations from the desired angle, and do not need to be constantly informed if they are holding the needle at the correct angle. The study tested their program with an experiment where participants attempted to touch the surface of a liquid under an electronic microscope with a needle and identify times of contact while keeping the needle at a specific angle. This is comparable to the task of injecting DNA into bacteria, because one would regularly locate a needle or syringe and a cell under a microscope using visual feedback from a computer-generated image when direct observation is impossible. The study found that using sonification to provide audio feedback on angle and location led to better precision than using a standard visual system. The study also found similarly positive results from using both sonification and the visual system, suggesting that a combination of audio and visual feedback may be ideal. [3]

Another sonification program, Cheddar, focuses on interactive spatial sonification [2]. Cheddar sonifies data with parameter mapping, and uses stereo to create the effect of sound moving in space. This allows users to shift their point of view when interpreting data, so they can look at data from different perspectives and thus notice features of data that are difficult or impossible to perceive otherwise. Cheddar bases its sonification on the density and spread of data. For example, it treats sizeable and spread out data from geological rock mechanics differently from data that is more compressed. The app sonifies up to six variables. Cheddar was intended to be used for both art and science, thus it supports more aesthetic mappings or more accurate mappings, according to the needs of artists and scientists. [2]

Sonification Sandbox is a Java-based program that is simpler and intended for non-professional use [8]. Most other sonification programs are made for niche audiences and often depend on software which is not commonly accessible, as many sonification programs are intended for AR systems with proprietary software. Since Sonification Sandbox is a Java-based application, it can be run on virtually any platform that supports Java. Sonification Sandbox is also accessible to a non-professional audience due to its intuitive interface, which allows users to map data in a spreadsheet to timbre, pitch, volume, and pan. In addition, the ability to import .csv files, a common file type for spreadsheets, allows users to edit the data set they wish to sonify in a program such as Excel, Google Sheets, or almost any spreadsheet editing software. Sonification Sandbox also allows users to edit data in a spreadsheet within the application and modify how the data is mapped to different sonification parameters. Once data and settings have been set, the program generates a graph of the data and a corresponding sonification, which can be exported separately as media files or together in an .htm file. [8]

G. Dubus and R. Bresin reviewed sonification strategies for 495 research projects sonifying physical properties and chose 60 projects to study in depth. They analyzed trends among sonification research, including the most common variables that were mapped to different characteristics of sound and the frequency of the use of various auditory dimensions. The table below summarizes their results. They found that fundamental frequency, or pitch, was the most common auditory dimension used in parameter mapping. [9]

Table 1. Most used mappings of sixty analyzed projects

Number of Occurences	Mapping
24	Location → Spatialization
18	Location → Pitch
12	Distance → Loudness
10	Density → Pitch
9	Distance → Pitch
8	Density → Duration
7	Orientation → Pitch
7	Size → Pitch
6	Velocity → Pitch
6	Motion → Pitch
6	Motion → Spatialization
6	Energy → Loudness
6	Signal amplitude → Loudness
6	Signal spectral energy distribution → Pitch

This tables summarizes the most frequently used mappings among the sixty projects analyzed by G. Dubus and R. Bresin [9].

Table 2. Most used mappings of sixty analyzed projects

Auditory dimension Percentage of the total number of mappings	Percentage of the total number of mappings	Number of auditory dimensions used significantly less often
Pitch	23.8	29 (100%)
Loudness	15.2	27
Duration	10.1	25
Spatialization	9.5	25
Tempo	5.9	21
Brightness	5.1	18
Timbre	3.6	14
Intrumentation	3.6	14
Spectral Power	2.8	9
Spectral Duration	2.4	5
Pitch Range	2.0	3
Center Frequency of Filter	2.0	3

This table summarizes the usage frequency of auditory dimensions among the sixty projects analyzed by G. Dubus and R. Bresin [9].

Learning Styles

There are multiple different learning style models, but one of the most important ones is the Visual-Auditory-Kinesthetic (VAK) learning styles model, which is based on student response and interpretation of external stimuli [7]. Though the three categories of learning styles are kinesthetic, visual, and auditory, most learners are some combination of the three [6].

Visual

Visual learners absorb information best through visual means. Facial expression along with body language and other visual cues are observed attentively by visual learners and influence the intake of knowledge. In addition, visual learners absorb information best from visual content of lessons such as diagrams and pictures. [6]

Kinesthetic

Kinesthetic learners are hands-on learners that learn through exploration and experimentation. They prefer to engage with material by touching and moving to examine the world around them. Kinesthetic learners also enjoy activity-based courses with experiments or activities involving physical movement, as investigative activities engage them and help them absorb information best. [6]

Auditory

Auditory learners use nuances of sound to help them absorb information. They often find listening to a teacher and other students or discussing material to be beneficial to their learning experience. In addition, auditory learners use pitch, speed, and tone of voice to help them gain understanding of lectures, similar to how visual learners use facial expression and body language. Courses geared towards auditory learners should include oral delivery or presentation rather than text alone. Although pure auditory learners are rare, many people are partial auditory learners, which means that many students can benefit from including auditory teaching elements in lessons. [6]

Joint and Combined Variation

Joint and combined variation is the topic in mathematics which is used to describe the complex relationships between three or more variables that vary directly and/or inversely with each other. Examples of combined variation include the ideal gas law and the equation for gravity, as they relate more than two variables and each pair of variables is either directly or inversely proportional. In addition, many chapters in textbooks on joint and combined variation address relationships in which one variable is proportional to another variable raised to some rational power, as this follows naturally from the concepts of joint and combined variation. Since joint and combined variation involve relationships between more than two variables, sonification may be an effective method for presenting examples of joint and combined variation, and may be especially useful for auditory learners.

Conclusion

Many techniques have been established for sonification, but the applications of sonification have yet to be thoroughly explored, especially the educational applications. Currently, sonification is mostly used by professionals, but tools like Sonification Sandbox allow educators who may not have much experience with sonification to sonify data in ways that can improve their lessons. Joint and Combined Variation is a topic where applying sonification is natural because the subject describes relationships between many variables which are difficult to exemplify visually. In addition, the impact of integrating sonification into education has not been widely examined, nor has the influence of sonification in lessons on auditory or partial auditory learners who may benefit the most from sonifications due to their learning style.

Project Plan

Researchable Question: How does integrating sonification into a lesson about joint and combined variation influence student comprehension?

Hypothesis: Integrating sonification into a lesson about joint and combined variation will improve student comprehension, especially for students that are auditory learners.

Plan

This project examined the impact of sonification on student comprehension through the use of a video lesson on joint and combined variation which included a sonification of the example relationship PV=nRT. There was also a lesson without sonification, and both lessons were electronically sent to middle school and high school students in a Google Form along with various surveys and tests. For further details, see Materials and Methods below.

Methodology

Lesson Creation

The lessons were created as a presentation in Power Point 365 (Office 365 was provided by the Mass Academy of Math and Sciences (MAMS)) which included a visual graph made in Excel 365 of the example relationship PV=nRT. Recording of the lesson was done using the screen-recording program Flashback Express (available online) and a standard microphone headset on a laptop with touchscreen capabilities which will allowed handwriting on the screen. The laptop was a Toshiba Satellite Radius 12 p25w-c2300-4k and ran Windows 10. Content for each slide was recorded in individual videos, then VSDC Free Video Editor (available online) was used to edit the videos together. For the lesson with sonification, the sonification was played at the end of the video with an explanation of how the sonification described the example relationship. These two lessons were uploaded to YouTube to provide easy integration into Google Forms. The videos are unlisted, but are accessible at the links https://youtu.be/jB3D9eaW4SI (lesson with sonification) and https://youtu.be/xUFh2gZbxoI (lesson without sonification).

Sonification Sandbox 6.2 beta, a free program from the Psychology Department's Sonification Lab at the Georgia Institute of Technology, was used to generate the sonifications.

The program allowed for data to be imported from Excel 365, so Excel was used to generate 216 data points resulting from all the possible combinations of the integers from one to six assigned to three independent variables representing n, V, and T in the relationship PV=nRT. Using equations in Excel, the value for a fourth variable, P, was calculated using an R value of 0.8. Using the settings in Sonification Sandbox, the timbre for voice 1, representing the variable T, was set to "Harmonica" and the volume set to 96%; the timbre for voice 2, representing the variable n, was set to "Marimba" and the volume set to 100%; the timbre for voice 3, representing the variable P, was set to "Church Organ" and the volume set to 100%; and the timbre for voice 4, representing the variable V, was set to "Violin" and the volume set to 100%. The global playing time was set to 60 seconds, though in the video lesson the sonification was paused. A visual graph of the relationship was also generated in Excel.

Electronic Form

Each lesson was put into a Google Form along with an introduction and background survey created by the researcher, a learning styles survey (used with permission from businessballs.com [7]), a pre-test created by the researcher, either the lesson with or without sonification, a post-test, and a feedback section created by the researcher. These Google Forms were then sent out electronically and taken by research participants following obtainment of informed consent forms.

Data Collection

The first round of testing was performed on juniors at MAMS. The data was used to make some edits to the forms and some was used for data analysis. Afterwards, a class of 21 seventh graders at the Advanced Math and Science Academy Charter School (AMSA), was surveyed. The seventh graders each took one of the Google Forms during a class period, and the researcher supervised and answered questions. A Wilcoxon Signed-Rank Test was run online [10] on the data to determine improvement based on pre-test and post-test scores. Improvement for students who received the sonification lesson and who did not receive the lesson with sonification was compared using an online Mann Whitney-U test calculator [11]. In addition, the student population was later restricted to students who were partial auditory learners, then to students with a musical background, and the same tests were run after each restriction.

Limitations and Assumptions

This project attempted a novel application of sonification, so there was little previous research in the field available on teaching a lesson with sonification. In addition, the five month time span and the minimum prior experience performing psychological studies limited the scope of the project. The sonification program used had a set number of instruments sounds available and could only support importing up to 255 rows of data.

The project assumed that participants were honest and followed form instructions to the best of their ability, that students understood the sonification of the example relationship at some level, and that students remained concentrated throughout the study and could read, hear, and understand the surveys and lessons. The data analysis assumed that trends observed in the data were representative of the global student population and that data were not affected by personal factors unrelated to education. The statistical tests used assumed that test scores were dependent on taking the lesson, that student responses were independent from each other, and some tests assumed that data was normally distributed.

Results

At AMSA, 9 students took the control version of the form and 12 students took the form with sonification, but 3 students who took the sonification form did not finish, so their responses were not considered. At Mass Academy, 13 students took the form with sonification and 13 students took the form without sonification. The scores on the pre-test and the post-test, and the number of questions answered of each VAK learning style category are shown below for each student. Improvement was calculated from the post-test score divided by the pre-test score. See full data in Appendix A.

Table 3a. Results from AMSA students (form without sonification)

Pre-Test	Post-Test	Improvement	V	A	K
2	3	1.5	4	4	2
3	3	1	1	1	3
2	1	0.5	5	5	4
3	2	0.67	4	4	2
2	2	1	1	1	1
3	3	1	5	5	1
0	2	--	1	1	7
3	4	1.33	3	3	4
2	3	1.5	1	1	3

This tables summarizes the scores on the pre-test and the post-test, the improvement, and the number of questions answered of each learning style category for each AMSA student who took the form without sonification.
-- indicates scores for which improvement could not be calculated

Table 3b. Results from AMSA students (form with sonification)

Pre-Test	Post-Test	Improvement	V	A	K
2	4	2	3	2	5
2	4	2	2	4	4
2	4	2	2	4	4
1	1	1	3	1	6
2	2	1	4	2	4
1	2	2	4	2	4
2	2	1	4	4	2
2	2	1	4	3	3
2	3	1.5	3	7	0
0*	3*	--*	0*	0*	0*
3*	2*	0.67*	4*	2*	4*
3*	2*	0.67*	4*	2*	4*

This tables summarizes the scores on the pre-test and the post-test, the improvement, and the number of questions answered of each learning style category for each AMSA student who took the form with sonification.
* indicates students that did not finish
-- indicates scores for which improvement could not be calculated

Table 4a. Results from Mass Academy students (form without sonification)

Pre-Test	Post-Test	Improvement	V	A	K
2	1	0.5	4	4	2
3	2	0.67	8	2	0
6	5	0.83	3	2	5
5	5	1	6	3	1
6	6	1	3	5	2
5	6	1.2	3	2	5
5	6	1.2	2	3	5
4	5	1.25	3	6	1
4	6	1.5	0	2	8
2	3	1.5	1	6	3
3	5	1.67	5	2	3
2	4	2	3	1	6
1	3	3	2	4	4

This tables summarizes the scores on the pre-test and the post-test, the improvement, and the number of questions answered of each learning style category for each MAMS student who took the form without sonification.

Table 4b. Results from Mass Academy (form with sonification)

Pre-Test	Post-Test	Improvement	V	A	K
6	5	0.83	4	3	3
2	2	1	6	1	3
6	6	1	4	2	4
6	6	1	3	2	5
6	6	1	5	4	1
4	4	1	2	6	2
5	6	1.2	3	6	1
4	6	1.5	6	1	3
4	6	1.5	2	3	5
4	6	1.5	4	4	2
3	5	1.67	5	4	1
2	6	3	6	3	1
1	5	5	6	3	1

This tables summarizes the scores on the pre-test and the post-test, the improvement, and the number of questions answered of each learning style category for each MAMS student who took the form with sonification.

Analysis

Since the students from AMSA and Mass Academy had very different backgrounds, the responses from each school were analyzed separately. The average and standard deviation were calculated for the pre-test and post-test scores and are summarized and graphed below. The population was then restricted to students who answered 4 or more questions on the learning styles survey that corresponded to being an auditory learner, and average and standard deviation were calculated for the pre-test and post-test scores of these students, and are summarized and graphed below.

Table 5a. Statistics from MAMS students (form with sonification)

All students	Pre-Test	Post-Test	Improvement
Average	4.08	5.31	1.63
median	4	6	1.2
st. dev.	1.64	1.14	1.11

Auditory learners	Pre-Test	Post-Test	Improvement
Average	4.4	5.4	1.27
median	4	6	1.2
st. dev.	1.02	0.8	0.27

This tables summarizes statistics from scores on the pre-test and post-test and the improvement of MAMS students who took the form with sonification.

Table 5b. Statistics from MAMS students (form without sonification)

All students	Pre-Test	Post-Test	Improvement
Average	3.69	4.38	1.33
median	4	5	1.2
st. dev.	1.59	1.59	0.62

Auditory learners	Pre-Test	Post-Test	Improvement
Average	3	3.6	1.45
median	2	3	1.25
st. dev.	1.78	1.74	0.84

This tables summarizes statistics from scores on the pre-test and post-test and the improvement of MAMS students who took the form with sonification.

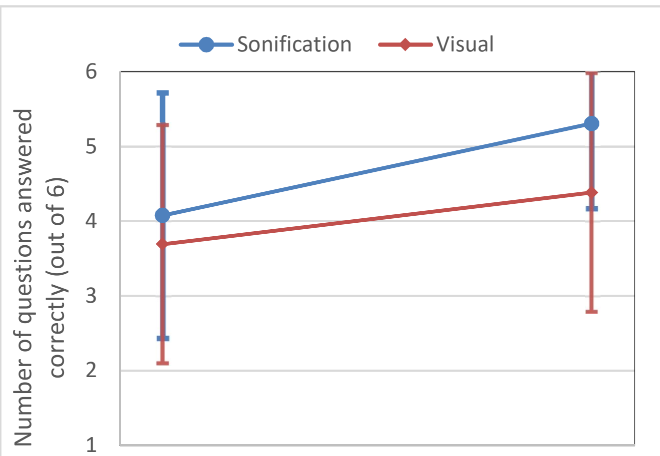

Figure 6a.

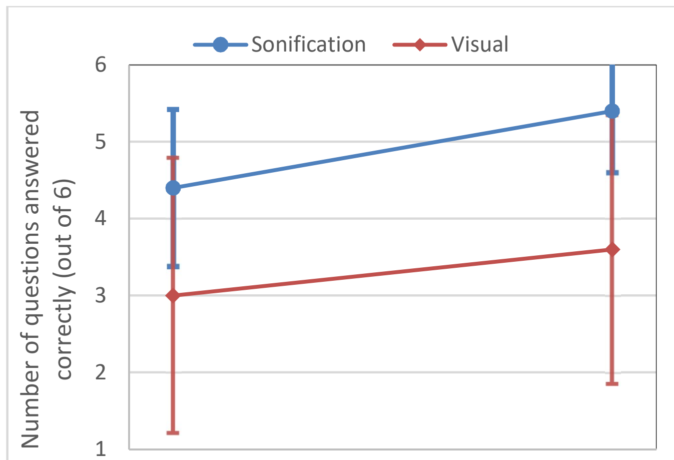

Figure 6b.

Figure 6. These graphs show the average pre-test (left) and post-test scores (right) of all MAMS students (6a) and just MAMS students who were auditory learners (6b). The error bars represent one standard deviation from the

A Wilcoxon Signed-Rank test was run [10] on the pre-test and post-test scores of Mass Academy students in each group, and significant improvement was found in each group. Among students who took the form with sonification (n=13), the sum of the signed ranks W=-33 and $n_s/r=8$, which qualifies as a .025 level of significance according to a table of significant values of W for small values of n_s/r [10]. Among students who took the form without sonification (n=13), the sum of the signed ranks W=-42, $n_s/r=11$, z-ratio=-1.89, and p=0.0329. A Mann-Whitney U test was run [11] on the improvement ratio of students in each lesson group, which resulted in a

U-value of 77.5, a z-score of -0.3333, and p-value of 0.3707. Among only students who answered four or more questions on the learning styles survey, which indicated a partial auditory learning style, the same test yielded a U-value of 20, a z-score of 0.07319 and a p-value of 0.4721. Among students with musical experience, the same test yielded a U-value of 20.5, a z-score of 0.0000, and a p-value of 0.5000. Though these results do not demonstrate significant impact from sonification, there was a ceiling effect due to the fact that many students at Mass Academy had a background on the topic so they scored perfectly on the pre-test.

Table 7a. Statistics from AMSA students (form with sonification)

All students	Pre-Test	Post-Test	Improvement
Average	1.77	2.67	1.5
median	2	2	1.5
st. dev.	0.41	1.05	0.47

Auditory learners	Pre-Test	Post-Test	Improvement
Average	2	3.25	1.62
median	2	3.5	1.75
st. dev.	0	0.83	0.41

These tables summarizes statistics from scores on the pre-test and post-test and the improvement of AMSA students who took the form with sonification.

Table 7b. Statistics from AMSA students (form without sonification)

All students	Pre-Test	Post-Test	Improvement
Average	2.22	2.56	1.06
median	2	3	1
st. dev.	0.92	0.84	0.34

Auditory learners	Pre-Test	Post-Test	Improvement
Average	2.6	2.6	1
median	3	3	1
st. dev.	0.49	1.02	0.38

These tables summarizes statistics from scores on the pre-test and post-test and the improvement of AMSA students who took the form with sonification.

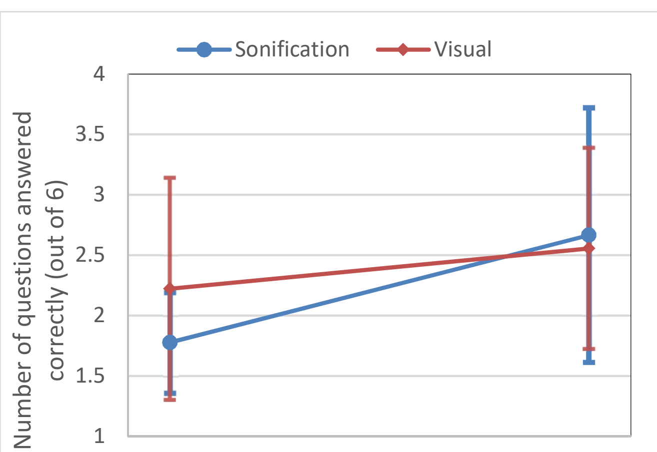

Figure 8a.

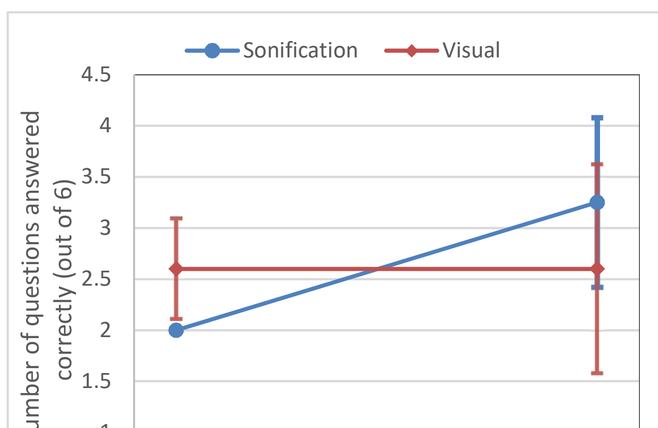

Figure 8b.

Figure 8. This graph shows the average pre-test (left) and post-test (right) scores of all AMSA students (8a) and just AMSA students who were auditory learners (8b). The error bars represent one standard deviation from the mean.

The same tests were run on AMSA students. Among students who took the form with sonification (n=13), the Wilcoxon Signed-Rank test [10] yielded W=-15 and $n_s/r=5$, which qualified as a .05 level of significance according to a table of significant values of W for small values of n_s/r. Among students who took the form without sonification (n=13), the test yielded W=-9 and $n_s/r=6$, which was not significant. The lack of significance may have been due to the small sample size. A Mann-Whitney U test was run [11] on the improvement ratio of students in each lesson group, which resulted in a U-value of 19, a z-score of 1.01547, and p-value of 0.05592. Among only students who answered four or more questions on the learning styles survey, which indicated a partial auditory learning style, the same test yielded a U-value of 14 and a p-value of 0.10591. Among students with musical experience, the same test yielded a U-value of 12 and a p-value of 0.6895.

The statistics were not in the range of significance, but the small sample sizes in both MAMS and AMSA students and the ceiling effect among MAMS students may have contributed to high p-values. However, the sonification did not significantly hurt student understanding, and when students rated the clarity of the sonification on a scale of 1 to 5 the average across both AMSA and MAMS students was 3.2727 with a std. dev. of 1.05, so many students understood the sonification. Also, the graph of average improvement for AMSA students (figure 8a) suggests that the lesson with sonification helped students more than the control lesson, but the large standard deviation for post-test scores of AMSA students who took the form with sonification reveals that students benefited varyingly from the sonification. The graph of auditory learners (figure 8b) indicates that auditory learners receive a greater, more consistent benefit from sonification. While the p-value of 0.05592 for improvement for AMSA students who took the form with and without sonification does not establish a significant difference, it implies that the trends observed warrant further investigation.

Discussion

As mentioned earlier, the small sample size and the ceiling effect in MAMS students limited the statistical analysis possible for this study, but the trends suggested certainly warrant further investigation. At AMSA, a late start and some technical difficulties with headphones affected timing, so not all students finished. The lesson with sonification was longer, so those students may have felt more rushed on the post-test. MAMS students did not take the lesson in a controlled environment, so data from MAMS students was more susceptible to environmental noise. Also, AMSA students had a strong scientific and mathematical background, which may have helped them understand the sonification more easily than other seventh graders. One surprising thing about the data was that musical experience did not noticeably impact how much students benefited from sonification. This may have been due to the small sample size and that all students that took the form with sonification indicated that they had played an instrument at some point in the past.

If the project was extended, more data would be collected to confirm the validity of the observed trends. Data could also be collected from students from many different schools so that mathematical background would be more varied. In addition, different sonification strategies could be employed and assessed, and students could be taught a subject over the course of multiple lessons to establish familiarity with sonification and processing auditory information. One possible application of integrating sonification into education might be teaching students with visual impairments or students with learning disabilities, as sonification may be an effective alternative to visual graphs for such students. If a suitable population of students with learning disabilities or visual impairments was willing to test the benefits of sonification, a mathematical lesson with sonification for such students could be designed and tested. In any case, the benefits of sonification in education are worth further investigation.

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Appendices

Appendix A: Full Data (Summarized)

Summarized data from MAMS:

Sonification Group						On a scale of 1 to 5:				Scale 1 to 5							
Timesta	Pre-Test	Post-Test	V	A	K	how was this form?	how was the Video	graph clarity	graph helpfulnes	sonificatio n clarity	sonification helpfulness	listen to music	play(ed) at least	sing/have you sung?	music theory		
01/01 5	6	5	4	3	3	3	3			3	Somewhat	4	In the past,	For fun	None/Never		
01/08 1	6	6	5	4	1	5	3			2	No	4	Currently, (	For fun	A little/Not in a serious setting		
01/19 1	6	6	3	2	5	5	3			1	No	2	In the past,	For fun	A little/Not in a serious setting		
01/31 1	6	6	4	2	4	4	3	4	Maybe	4	Somewhat	5	Currently, (	Never	A little/Not in a serious setting		
01/31 6	4	4	2	6	2	4	3	4	Maybe	3	Somewhat	3	In the past,	Never	A little/Not in a serious setting		
01/31 7	2	2	6	1	3	5	3	4	Yes	2	No	5	Currently, (	For fun	None/Never		
01/31 7	5	6	3	6	1	4	3	3	No	3	Somewhat	4	Currently, s	For fun	A little/Not in a serious setting		
01/04 2	4	6	6	1	3	5	4			1	No	4	In the past,	Never	None/Never		
01/31 1	4	6	2	3	5	5	5	5	Yes	4	Yes	5	In the past,	Never	A little/Not in a serious setting		
02/02 1	4	6	4	4	2	4	5	4	Maybe	3	Somewhat	3	In the past,	Formally (i	None/Never		
01/27 6	3	5	5	4	1	5	4	4	Yes	4	Somewhat	4	In the past,	Never	None/Never		
01/30 1	2	6	6	3	1	5	5	5	Yes	5	Yes	4	Currently, (	For fun	None/Never		
01/26 9	1	5	6	3	1	4	5	3	Maybe	3	Somewhat	4	Currently, (	For fun	A little/Not in a serious setting		
	1	2				Average	Average	Average	N:S:Y ratio	Average	N:S:Y ratio						
Average	4.0769	5.307692	4	3	2	4.461538	3.769231	4	1:4:4	2.923077	4:7:2						
median	4	6															
st dev	1.639	1.135756															
Visual Group																	
01/22 3	2	1	4	4	2	5	4	3	Somewhat			3	In the past,	Never	None/Never		
01/29 1	3	2	8	2	0	3	2	2	No			3	In the past,	For fun	None/Never		
12/31 5	6	5	3	2	5	3	3	1	No			4	Never	Formally (i	A little/Not in a serious setting		
01/04 1	5	5	6	3	1	4	4	4	No			3	In the past,	For fun	None/Never		
01/27 1	6	6	3	5	2	5	5	4	Somewhat			4	Never	Never	None/Never		
01/12 9	5	6	2	3	5	4	5	2	Somewhat			5	Currently, s	For fun	A little/Not in a serious setting		
01/27 1	5	6	3	2	5	5	5	4	Somewhat			4	Currently, (	For fun	A little/Not in a serious setting		
01/27 8	4	5	3	6	1	4	2	2	Somewhat			5	Currently, s	Formally (i	Yes, in a serious setting		
01/22 3	2	3	1	6	3	5	3	4	Somewhat			3	In the past,	For fun	A little/Not in a serious setting		
01/31 6	4	6	0	2	8	5	5	4	Somewhat			4	In the past,	Formally (i	A little/Not in a serious setting		
01/07 1	3	5	5	2	3	4	4	4	Yes			5	Currently, s	Never	Yes, in a serious setting		
01/27 8	2	4	3	1	6	3	5	5	Yes			5	Currently, (	Formally (i	None/Never		
01/27 1	1	3	2	4	4	3	4	3	Somewhat			5	Currently, (	For fun	A little/Not in a serious setting		
	1	2				Average	Average	Average	N:S:Y ratio								
Average	3.6923	4.384615	3	3	3	4.076923	3.923077	3.230769	3:8:2								
median	4	5															
st dev	1.5877	1.595111															

Summarized data from AMSA:

Sonification Group							On a scale of 1 to 5:				Scale 1 to 5							
Timestamp	Pre-Test	Post-Test	Improvem	V	A	K	how was this form?	how was the Video	graph clarity	graph helpfulness	sonification clarity	sonification helpfulness	listen to music	play(ed) at least	sing/have you sung?	music theory		
8:55:58	2	3	1.5	3	7	0	3	3	2	No	3	No	2	Currently,	For fun	A little/Not in a serious setting		
8:48:38	2	4	2	2	4	4	5	4	3	No	4	Somewhat	4	In the past,	For fun	A little/Not in a serious setting		
8:50:41	2	4	2	2	4	4	5	4	3	No	4	Somewhat	4	In the past,	For fun	A little/Not in a serious setting		
8:50:50	1	1	1	3	1	6	2	2	1	No	4	Somewhat	5	Currently,	Never	None/Never		
8:53:03	2	2	1	4	2	4	5	4	5	Yes	3	Somewhat	5	In the past,	Never	None/Never		
8:54:18	2	2	1	4	4	2	2	2	2	No	3	Somewhat	3	In the past,	For fun	None/Never		
8:54:22	2	2	1	4	3	3	4	4	3	Somewhat	4	Yes	3	Currently,	For fun	None/Never		
8:47:46	2	4	2	3	2	5	3	2	4	Somewhat	4	No	4	Currently,	For fun	None/Never		
8:53:18	1	2	2	4	2	4	5	3	3	No	5	Yes	4	In the past,	For fun	None/Never		
The next three responses were not considered in data analysis because the students did not finish																		
8:56:17	0	3		0	0	0	3											
8:58:20	3	2	0.666667	4	2	4	3	2	3	No	3	No	5	Currently,	Formally (i	Yes, in a serious setting		
8:59:52	3	2	0.666667	4	2	4	2	4	3	No	3	No	1	In the past,	Never	None/Never		
	1	2					Average	Average	Average	N:S:Y ratio	Average	N:S:Y ratio						
Averages a	1.833333	2.583333	1.348485	3	3	3	3.5	3.090909	2.9091	8:2:1	3.6363636	4:5:2						
median	2	2	1.5															
st dev	0.41574	1.054093	0.471405															
without last three responses:			1.5	3	3	4	3.777778	3.111111	2.8889	6:2:1	3.7777778	2:5:2						
Visual Lesson																		
8:56:18	0	2		1	1	7	3	3	3	No			4	In the past,	For fun	A little/Not in a serious setting		
8:56:33	3	4	1.333333	3	3	4	4	3	2	No			5	In the past,	Formally (i	A little/Not in a serious setting		
8:49:51	2	3	1.5	4	4	2	3	3	5	Yes			4	In the past,	For fun	None/Never		
8:50:43	3	3	1	1	1	3	2	1	1	Somewhat			4	In the past,	For fun	None/Never		
8:53:53	3	2	0.666667	4	4	2	3	4	2	Somewhat			4	In the past,	Never	None/Never		
8:54:13	2	2	1	1	1	1	3	4	5	Somewhat			2	In the past,	Never	None/Never		
8:54:51	3	3	1	5	5	1	2	1	3	Somewhat			3	Never	Never	None/Never		
8:56:59	2	3	1.5	1	1	3	5	2	1	No			5	Currently,	For fun	None/Never		
8:53:08	2	1	0.5	5	5	4	3	2	1	No			3	Currently,	For fun	Yes, in a serious setting		
	1	2					Average	Average	Average	N:S:Y ratio								
Averages a	2.222222	2.555556	1.0625	3	3	3	3.111111	2.555556	2.5556	4:4:1								
median	2	3	1															
st dev	0.916246	0.831479	0.34296															

Appendix B: Project Notes

Contents

Table of Contents

Knowledge Gaps

This list provides a brief overview of the major knowledge gaps for the project, how they were resolved, and where to find the information.

Knowledge gap	Resolved By	Information is located
Sonification Techniques	Reading	SonifEye: Sonification of Visual Information Using Physical Modeling Sound Synthesis; Interactive Spatial Sonification of Multidimensional Data for Composition and Auditory Display
Sonification Relevance	Reading	All sources concerned with sonification (e.g. SonifEye: Sonification of Visual Information Using Physical Modeling Sound Synthesis)
Sound Analysis	Reading	All sources concerned with music (e.g. SonifEye: Sonification of Visual Information Using Physical Modeling Sound Synthesis)
Fourier Series	Reading	Fractal Music : The Mathematics Behind “Techno” Music
Instrument Use	Testing	lab notebook
Software Use	Testing	lab notebook

Literature Search Parameters

These searches were performed between 9/16/18 and 2/15/2019.
This is a list of the keywords and databases used during this project.

Database/search engine	Keywords
WPI library search engine	Sonification, technique(s), sound, aesthetics, avoiding alarm fatigue, minimal training, spatial sound synthesis, parameter-mapping sonification, interactive sonification, alarm fatigue (sonifeye), Fractal, music, mathematics, Fourier Series, physical modeling, Curvature, e-learning, learner’s styles
Google Scholar	Sonification, education, learning style, sonified graphs

General Background

- There are four main types of sonification, as described in Interactive Spatial Sonification of Multidimensional Data for Composition and Auditory Display (the words taken directly from this source.)

1. Audification, described in Chapter 12 of *The Handbook*. This is a method that interprets a data sequence directly as an audio waveform.
2. Parameter mapping, described in Chapter 15. Changes in the sound are mapped from the data.
3. Stream-based sonification—features emerge through stream-based gestalts, similar to parameter mapping and, likewise, described in Chapter 15.
4. Model-based sonification, described in Chapter 16. Data are turned into dynamic models that the user "excites" to explore data structures via the acoustic feedback. ≫

- (Same paper) Continuous trajectories through space could be mapped to time, and work well with parameter-mapping, but this gives only one locational look at the data
- Mapping of many data sets can become processor-intense

- (The Sonification Handbook Chapter 18.2): There is a significant difference between hearing and listening, and what Gaver calls "everyday listening" and "musical listening." In everyday listening, we observe generally properties of sound to figure out qualities of an object associated with an object, like its size, material, etc. In musical listening, we play close attention to the sound in and of itself, and analyze it as we hear it.
    - In order for sonification to be effective at presenting data, it must be presented in a way that takes into account how the user is listening. Generally, the listener needs to be doing "musical listening," but this can be hard if the data is presented in a way that is hard to differentiate from noise.
- (Chapter 18.3.1): Various studies have showed that having representative/analogous sounds (real world sounds associated with what the data is presenting, for example, a glass-breaking sound to signify bottles breaking) in sonification can make it more effective and less annoying to the user.

- (Chapter 18.3.2) This book also talked about weather sonification (a path I was originally somewhat interested in), and studies that show that weather forecast data rendered as sound and then played regularly on the radio would not be found annoying or distracting.
- (Chapter 18.4) Sonification has been used for a while in computer debugging. An advantage of sonification is that the brain can passively listen to auditory input. The book mentions various "attempts at [computer] program sonification"
    - Simple mapping of "a data item to a chromatic pitch in the 128-tone range"
    - Aestheticism allowed more comprehensible output
    - (citation people) "mapped chaotic attractor functions to musical structures in which the functions' similar but never-the-same regions could be clearly heard"
    - "1994 Northridge, California earthquake" along with the bubble-sort algorithm were sonified using musical forms
    - Using sonification to complement visual displays was also effective
    - Book then lists various developed "program sonification tools" and gives some information about each one
- (Chapter 18.5) Gaver developed a sonification system in Finder to measure progress by the sound of a jug being filled up
- (Chapter 18.6) Some challenges in sonification include
    - Sonifications being annoying, hard to listen to, or distracting
    - Aestheticism
    - Being comprehendible and hearable
- (18.6.2) "Emotive associations" are important to consider
    - There is some emotion conveyed when presenting weather information, like the happy emotion from hearing nice weather, which is not conveyed when sonified
        - One group tried to solve this by developing an "Emo-Map" which connected weather vectors with emotions
- (18.6.3) There seemed to be a lack of "formal studies" about which "ecology" is best perceived by users (voice vs sound effects vs combinations, etc.)
- (18.7.3) Soundscapes are a cool way of relating real world information in sonifaction, as natural, real-world sounds are built into the soundscape

- (18.7.5) Physical modeling is cool, because instead of direct parameter-mapping, data is mapped to a physical model which is then mapped to sound, which allows for more realistic and applicable sonifcations

SonifEye: Sonification of Visual Information Using Physical Modeling Sound Synthesis

Source citation

(Roodaki, Navab, Eslami, Stapleton, & Navab, 2017)
https://ieeexplore-ieee-org.ezproxy.wpi.edu/document/8007327/
Roodaki, H., Navab, N., Eslami, A., Stapleton, C., & Navab, N. (2017). SonifEye: Sonification of Visual Information Using Physical Modeling Sound Synthesis. *IEEE Transactions on Visualization and Computer Graphics, 23*(11), 2366-2371. doi:10.1109/tvcg.2017.2734327

Source type

Journal Article

Keywords

Sonifaction, techniques, aesthetics, avoiding alarm fatigue, minimal training

Summary

For tasks requiring high precision, visual feedback doesn't always cut it, so this paper used sonifications for feedback. They tested poking objects, and found good results for sonification, also good but less good results for combining visual feedback and sonification. Alarm fatigue is really the big problem that is eliminated by sonification. Also, mapping accuracy to pitch and timbre, not just pitch, makes things more intuitive, and continuous signaling is distracting.

Note: for other articles see abstract

Reason for Interest

This article contains a technique for sonification, which is what I was looking for in my initial research.

Notes

Abstract

- There are advantages to "Sonic interaction as a technique for conveying information" over standard visual methods, especially due to elimination of distraction
- "aesthetics, the cognitive effort required for perceiving information, and avoiding alarm fatigue are not well studied in literature" and are not well implemented in standard techniques
- This paper presents a method that allegedly requires "minimal training" and is good for tasks "requiring extreme precision."
- Two experiments allegedly show this method of sonification superior to standard methods.

Introduction

- Visual AR is rapidly progressing and proving useful in science, such as in medical professions
- "multisensory AR" would be even better, as you can track more variables, but doesn't currently exist in as good a form as visual AR
- Hearing sense is good to add because its "omnidirectional," and "gives a subject the capability to articulate the nuances of complex sonic environment"
- Background:
    - Sonification is gaining influence in science because of its pros
        - Vision already almost overloaded, so offload extra variables to sound

    - "Using auditory cues to indicate the occurrence of an event or conveying spatial or mechanical information has proven to be effective and reliable [11]."
  - Sonification and parameter mapping "is not directly comparable" to visualization
  - "alarm fatigue" – sensory overload "could lead to misinterpretation or loss of significant information"
  - Aesthetics improve work environment of users and bystanders/subjects
  - Intuitivity is good for making subconscious associations that help recognize stuffs
  - (citation) found pitch is most commonly used parameter
    - Most important variable to pure frequency
  - Conclusion that reference sounds are needed for an "interactive system"
  - "physical modeling sound synthesis" – generate sounds associated with known "natural phenomena"
    - Allows for more intuitivity
    - Decrease "cognitive load" and alarm fatigue.
- Previous Work
  - (citations) physical modeling has been done well by "Modalys" and [8], and captures the many sound aspects of an object
  - Shelly et al. experiment (citation) mapped curvature of an object to sound in a way that made intuitive connections even by non-experienced users
    - "physical modeling leads to less cognitive load" but still very understandable
  - Other studies (citation) show that physical modeling is feasible

Methods

- Vision isn't enough sensory input for some tasks like working under a microscope.
- "three sonification mechanisms are introduced that employ sound synthesized by physical modeling to embody touch, applied pressure and angle of approach in high precision tasks regardless of the sensing method"
- To sonify action/moment of "gently touching a surface," "recorded acceleration on impact is mapped directly into the sound volume and is inversely proportional to the elasticity of the virtual membrane"
  - Like sound of touching an egg yolk that jiggles
  - Inverse proportion done so that when slow+careful approach, don't miss low notes
- Pressure mapped to taps on wood/metal
  - As increasing to maximum pressure, time between taps becomes shorter and sound becomes more metallic
  - Soft threshold for "desired pressure" and "high but tolerable pressure"
  - Hard threshold for "maximum tolerated pressure"
  - "The difference between the soft threshold and the current applied pressure is inversely mapped to the sound volume as a guide to target" according to the function
    - $v(c) = \frac{c^2 - c}{t^2 - t}, \quad v, c, t \in [0, 1]$
    - "v is the sound volume level of the playback device, c is the current pressure, and t is the soft threshold"

- Material of plate has input described by the function
  - $$\begin{cases} \mathrm{p(c)} = \frac{\mathrm{m-w}}{\mathrm{T}}\mathrm{c} + \mathrm{w} \;\; \mathrm{c} \in [0,\ \mathrm{T}] \\ p(c) = m \;\; c \in (T,\ 1] \end{cases}$$
  - "T is the hard threshold, c is the current pressure, and $P(c)$ holds a value between w and m for wood and metal respectively which is then mapped to a vector of values responsible for the material the virtual plate is constructed from"
  - Not specific icons, but gradual shift
- Angle/pose mapped to frequency, based of "desired" angle/pose
  - Uses inverse squares, and not continuous, because this annoys and distracts the user less, alleviating some of the cognitive load while still guiding
- Many mathematical models for sound synthesis, this experiment uses the one of Modalys for aesthetics

Experiments

- Designed to compare "environments that are augmented only visually, solely aurally or with both techniques simultaneously"
- Desire high precision
- Error measures recorded separately
- Task 1
  - "use a digital stylus on a digitizer board…to track a moving object [(a circle, which moves with random direction and speed)] while keeping the pressure applied by the stylus at a target value that changes over time"
  - 3 feedback systems
    - Above sonification system
    - Visual color gauge on side with target and current pressure
    - Both feedbacks given
  - 6 Mock trials then real data collection
- Task 2
  - "Test subjects are asked to move a needle with a diameter of 0.3*mm* towards a transparent and highly viscous liquid and gently touch it while maintaining a certain angle" "under the surgical microscope while looking through the ocular lenses."
  - OCT image of needle and liquid, "computer vison techniques" to show angle, distance, etc., passed on 3 ways
    - "the OCT image and the target angle line are rendered onto a Heads-Up Display (HUD)" that can be seen through the lens of the microscope
    - HUD only shows "raw OCT", "angle and touch" sonified using the "proposed sonification method"
    - Both feedback given
  - 2 trial runs
  - Testers need to press a pedal every time they touch the surface, and keep at specified angle

Results

- Task 1
    - Best was pure sonification, worst was pure visualization, both in the middle for tracking the circle
    - For pressure, avg % error is 1.73 for pure visualization, 2.04 for sonification, and 1.69 for both; stdev same for sonification and both, higher for pure visualizaition
- Task 2
    - Accuracy for angle was avg 5.06 degrees off for pure visualization, 4.31 off for pure sonification, 4.64 off for both
    - For knowing when liquid was a touch, pure sonification and both were equally better than pure visualization

Discussion

- Improved accuracy when some visual information substituted for sound, though having both still helps
    - Sonification means you don't have to restrict field of view
    - Also, sound comes from everywhere, so you don't have worry about tracking errors
- In task 2, subjects had no training which explains why they were generally bad
    - Method of physical modeling allows natural associations which make it more intuitive
        - Having instrument change rather than just pitch change means less training needed
    - Having both visual and audial feedback doesn't take anything away, but does give some improvement in accuracy
    - Excuses given
    - Overall, "both experiments show feasibility" of the methods they used.

Conclusion

- Contributed model to follow
- Aimed to use "physical sound synthesis" for feedback, and thus improve accuracy in "high precision tasks"
- Restating intro
- Results show effectiveness of methods
- Future directions: feedback for tasks which "require[e] rapid reactions", generally improving current systems
- Real world testing is useful+important

Questions/Other

Interactive Spatial Sonification of Multidimensional Data for Composition and Auditory Display

Source citation

Barrett, N. (2016). Interactive Spatial Sonification of Multidimensional Data for Composition and Auditory Display. *Computer Music Journal* 40(2), 47-69. The MIT Press. Retrieved September 16, 2018, from Project MUSE database.

https://muse-jhu-edu.ezproxy.wpi.edu/article/620161

Source type

Journal Article

Keywords

spatial sonification of multidimensional data, spatial sound synthesis, parameter-mapping sonification, interactive, minimal training, ambisonics

Summary

- Interactive and integrated approach to spatial sonification design
    - Interaction between time and space
- Being able to move in space in relation to data lets people see things they couldn't otherwise
- Considers aesthetics
- Combining many previous techniques into his
- "higher-level construction showing the interdependence of data, sound, interaction, aesthetics, science, and music"
- Can be used for science or art, small or big scale data
- Future application: creating "test material" and studying "geological faulting" and art composition
- Future expansion: adding sample outputs, recording function

Reason for Interest

This paper presents a method of sonification similar to something I was planning on building, an easy to use app.

Notes

Abstract

- This paper presents a new approach to modeling multi-dimensional data.
- The approach employs parameter-mapping sonification
- "Implemented in an" interactive "application called Cheddar", coded in "Max/MSP"
- "User can modify" sound and space parameters in real-time
- "Draws on existing literature" and author's background, but new and improved
- "Spatial information is sonified in high-order 3-D ambisonics, where the user can interactively move the virtual listening position" to gain better insight to the data, unlike previous applications. Generally high-def/high-tech
- Easy to use and requires "no specialized knowledge of programming, acoustics, or psychoacoustics"
- Allegedly bridges the gap "between science and art" to allow for more flow between the two disciplines

Introduction

- “Sonification in 3d space” allows for a useful way to interpret scientific data
    - The 3d allows for different perspectives
- Sonification is already used for various fields such as navigation and interpreting brain data (citations in paper)
- “Spatial elements [in music] have historically been a compositional concern” and were generally used to create an immersive and rich experience
- Sonification can somewhat fix this problem, and take “the focus” away from “visual impressions”
- In general, artists care more about aesthetics in sonification, while scientists care more about accuracy and precision, but it’s a blurry line
    - Aesthetics can be useful to be able to listen to long tracks
    - Accuracy is good for sonification to reflect data
    - Interactivity of a sonification program allows the user to prioritize what they want
- This article presents the author’s work on the application Cheddar, which interactively sonicates data
- The work “draw[s] on spectromorphological conceptualizations of sound and spatial behavior,” various previous (cited) work on sound and sonification, and “how intrinsic features…and intrinsic features…interact”
- The app has undergone extensive development and presentation and reworking by the author
- First part of the article shows “underlying research and the design choices” of the app, and the second part “specific application of these choices in Cheddar” and then conclusion presents “practical applications” of the app.

Underlying Research and Design Choices

- “begin[s] by investigat[ion]” of “sonification techniques and” relevant data sets
- Then how we perceive “auditory space” and “a discussion” of past sonification programs that “display spatial differences” and their “practical applications”
- Then role of “aesthetics” and “practical considerations” in design
- Sonification Options and Data Sources
    - Four main sonification techniques (cited from *The Sonification Handbook*)
- <<□ 1 . Audification, described in Chapter 12 of *The Handbook*. This is a method that interprets a data sequence directly as an audio waveform.
- □ 2. Parameter mapping, described in Chapter 15. Changes in the sound are mapped from the data.
- □ 3. Stream-based sonification—features emerge through stream-based gestalts, similar to parameter mapping and, likewise, described in Chapter 15.
- □ 4. Model-based sonification, described in Chapter 16. Data are turned into dynamic models that the user “excites” to explore data structures via the acoustic feedback. ≫
    - “collaborations with scientists provided useful insights into the challenges of spatial data”
        - For example, data from “geological rock mechanics” was discrete but “sizable,” which could make it challenging to have real-time sonification
        - There was problems with result not being heard, so “filtering data”, “different types of sound input”, “data reduction”, and “manipulating the temporal duration” were considered.

- Continuous trajectories through space could be mapped to time, and work well with parameter-mapping, but this gives only one locational look at the data
- Cheddar was designed to handle wide ranges of data, and to be modular
  - Handles "six variables at any one time" and turns into sound
  - Processing power determines how many data sets can be sonified at the same time
- Paper identifies a competitor, "SonEnvir," which is modular, but requires programming knowledge and "limited" "real-time interaction"
  - De Campo made a design map which is based off of "the number of data points" (x-axis), "the number of properties of interest for each data point" (y-axis), and "the number of streams estimated to be suitable for meaningful data representation" (z-axis)
  - This data map was used to determine how to sonify the data
    - For example, density of data can be adjusted to make sonifications more audible or distinguishable.
    - The data map also allows for continuous adjustment of "data rate, data reduction, and a number of other parameters," and means tempo doesn't have to be initially decided
    - This data map can help the program and subsequently the user better interpret the data

- Direction, Distance, and Polyphony
  - Localization blur of sound gives angle (direction), and ears blur sound location
  - Moving through the "spatial scene" clarifies some ambiguities caused by ^^
  - Distance hard to detect with sound (though we're better at gauging relative distances), so not processor prioritized
  - Drawing on previous (cited) work
- Previous Applications of Spatialization in Sonification
  - "Vector-based amplitude panning" (VBAP) is done with 3 speakers in space
  - "higher-order ambisonics (HOA)…captures…3-D sound in spherical harmonics describing the sound field" then converts it to sound file
  - "Wave field synthesis (WFS)…synthesizes the wave fronts of virtual spatial sounds by using a large number of individually driven speakers, based on the principle that the wave front can be regarded as a superposition of elementary spherical waves, but WFS has not be applied to any extent in sonification"
  - Cited application examples, but each don't have enough interactivity
  - Cheddar used HOA
- Aesthetic Discussions on Sound Design
  - "casual mappings" – mappings where sound ← action related to it
    - More natural than "arbitrary mappings"
    - Natural → more aesthetic and recognizable
    - Seemingly small changes can make a natural sound unnatural
  - Repetition can cause problems
  - Organization makes sonification aesthetic and comprehensible
  - Imitation can make sonification more logical, but accuracy needs to be considered, especially in science
    - Science usually more abstract

    - Emmerson's "language grid" is a tool to connect sonification for science and art
- Interaction, Interface, and Program Design Options
    - simple interface, real time access to parameters is hard but ideal
    - controller

Cheddar (section)

- "six variables: 3-D spatial data, two free-choice variables, and either a fixed or a data-defined variable time step"

Table 1. Cheddar's Main Features

SONIFICATION METHOD
Parameter-mapping sonification
Sound and space as information carriers
Interactive and real-time auditory display
One application useful for music and science

SOUND
A selection of presampled sound inputs or user created sounds
A selection of test signals (saw tooth, sine wave and filtered noise)
Granular approach: a sound or sound section is triggered for each data point
Grain transformations:
Attack and decay amplitude envelope
Duration
Pitch transposition
Volume
Band-pass filter center frequency (for noise inputs)
Attack enhancement
Equal-loudness compensation (50-phon contour)
Individual processing for each sound grain for all transformation parameters
A density of up to 14 overlapping grains per data set
Simultaneous processing of multiple data sets
Spatialization encoded in high-order ambisonics
Spatialization decoded to any loudspeaker array or to binaural sound

INPUT DATA
Discrete-event time-series data sets containing up to six variables per data set
Up to 1msec timing accuracy
Data loaded as files or streamed in real-time from an external source
Data filtering to focus on selected values (high-, low-, band-pass)
Automatic detection and real-time update of data ranges passed to the mapping stage
Modular design to tailor Cheddar for different computer speeds

MAPPING
Data is read at a user-defined time step or as a variable specified by each data point
Unique sound can be allocated for each data set
Three variables control spatial location of the sound grain
Any data variable can be mapped to pitch transposition, band filter or to signal frequency
Any data variable can be mapped to volume, sound grain duration, or attack slope

REAL-TIME CONTROL
Sound transformation scaling ranges
Data rate for preloaded data files
Data decimation
Spatial listening location
Spatial rotation transformations
Data event range passed to the sonification
Reverberation level
All scaling parameters simultaneously transformable using MIDI faders

- "listening location" changes volume and reverberation
- Testing and Application
    - To create associations, they made sonifications of physical gestures
    - "space–time relationships are a key factor in gestural expression"
    - listening location matters

Questions/Other

A Systematic Review of Mapping Strategies for the Sonification of Physical Quantities

Source citation

Dubus, G., & Bresin, R. (n.d.). A Systematic Review of Mapping Strategies for the Sonification of Physical Quantities.(Research Article). PLoS ONE, 8(12), e82491. doi:10.1371/journal.pone.0082491

Source type

Journal Article

Keywords

Review, Sonification Techniques

Summary

See Abstract

Reason for Interest

This will help me gain background knowledge of how to implement sonification, and can also serve as a reference.

Notes

Abstract

- Serves to organize and summarize sonification techniques in experiments.
- Get trends and help future sonification design
- "list of conceptual dimensions" and "frequency of use"
- pitch is most used, "spatial auditory dimensions" are used for "kinematic quantities"
- not many paper evaluate "sonification mappings"
- Ends with proposing "a mapping-based approach for characterizing sonification"

Introduction

- Overview of 179 publications "in order to identify established methods and techniques."
- auditory dimensions - "psychophysical and physical dimensions of the resulting sound"
- Section 1: "concept of sonification
- Section 2: "systematic review"
- Section 3: building database and "extracting data"
- Section 4: "brief description" of sixty projects
- Section 5: Analysis
- then suggests future work
- Nature of Sonification
    - "(International Conference on Auditory Display – ICAD) was founded in 1992"
    - development of definitions
        - Gray and debated boundaries
- Character
    - Good for interpreting data, kinesthesia, "sensory substitution"
    - Quotes *The Sonification Handbook*, parameter-mapping is most-common used method
    - Model based sonification – like physical modeling discussed in other papers, "virtual sounding object"

        - Seems preferred
- Historical perspective
    - Mesopotamians used audition to “detect anomalies in accounts of commodities”
    - Many throughout history
    - Stethoscope, Geigner counter (for measuring radiation)
    - More recent explosion

(from the end)

Conclusions and Perspectives

- First made database of 739 entries, then randomly selected 60 project (“179 scientific publications")
- Analyzed things like “level of synthesis, the nature of the sound, and the software platform used”
- List of “conceptual dimensions” and “auditory dimensions”
- Restates abstract
- Results also supported the “hypothesis: the most popular mappings follow the logic of ecological perception.”
- For future sonification projects or sonification research, one should consider these most-common approaches of parameter-mapping, pitch and/or “natural perception”
- Characterization of sonification via mappings
    - “all works that were included contain at least one description of a sonification mapping from a physical dimension to an auditory dimension”
    - “various specificities of the nature of sonification…can be expressed…by imposing restrictions on the domain and on the codomain” “of mappings”
    - Future characterization could be based off mappings technique

(back to section 2)

Motivations

- Organize current research which will serve as a reference for future sonification projects
    - Identify common techniques and trends
- Lots of citations of preview overviews
- When domain and range can be ordered, “the mapping is said to have a polarity if [it] is monotonic
- A previous database of mappings “was meant to organize sonification mappings according to three design components: nature, polarity, and scaling of the mapping”
- “pbysical” domains make mapping nice, so that’s what is studied here

Methods

- Lists databases
- Focused only on “physical quantities”
- “intermediate-level dimensions” were grouped, like density of people or saturation of chemical
- Focused on “perceptual effects rather than sound synthesis techniques”
- “best solution is probably to have a multi-level and multi-scale structure for the classification of both physical and auditory dimensions

Presentation of Data

- 179 articles in paper, others online

- 33 physical dimensions, which “are distributed over five high-level categories: kinematics, kinetics, matter, time, and dimensions (table)
- 30 auditory dimensions, which “are distributed over five high-level categories: Pitch-related, Timbral, Loudness-related, Spatial, and Temporal (table)
- Table later summarizes 60 projects
- “multiple occurrences” of similar “low-level dimensions” are counted as same

Results and Discussion

- “principal measure considered…is the frequency of use of mappings”
- Preliminary hypotheses based on analysis of some articles:
    - “A large proportion of sonification mappings follow the logic of ecological perception.”
        - “natural perception”
    - Pitch is “most used auditory dimension”
    - “Spatial auditory dimensions are almost exclusively used to sonify kinematic physical quantities.”
- BIG Table in article (many pages, summarizes 60 projects)
- Data supports hypotheses (1 and 3 in 5.1.2)
    - One example of type of mapping that doesn’t support or contradict H1
- 5.1.3 (supporting H2)
    - Found part-whole ratio of auditory dimensions, then “We performed pairwise Student’s t-tests”
- 5.1.4
    - In the “category Kinematics: Pitch-related and Temporal auditory dimensions were found to be used significantly more often than Loudness-related auditory dimensions”
    - In the “category Kinetics: Spatial auditory dimensions were found to be used significantly less often than [other] auditory dimensions”
    - t-tests

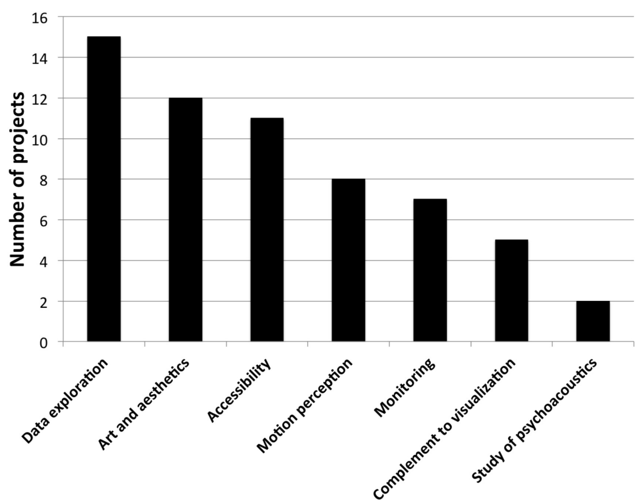
Table 7. High-level trends in the distribution of mapping occurrences.

	Pitch-related		Loudness-related		Temporal		Timbral		Spatial	
	N_m	%	N_m	%	N_m	%	N_m	%	N_m	%
Kinematics	64	26.8	30	12.6	53	22.2	45	18.8	47	19.7
Kinetics	19	22.4	24	28.2	19	22.4	19	22.4	4	4.7
Matter	22	29.3	11	14.7	19	25.3	23	30.7	0	0.0
Time	17	25.0	8	11.8	17	25.0	24	35.3	2	2.9
Dimensions	20	32.3	6	9.7	15	24.2	18	29.0	3	4.8

Distribution of mapping occurrences aggregated in high-level categories for both physical and auditory domains. The number of mapping occurrences identified is

-
    - “normalized the number of mapping occurrences in each high-level category in the physical domain against the total number of mapping occurrences”
    - Note on how time is more used than shown in results, as they didn’t count instantaneous to instantaneous
- 5.1.5
    - Table of intermediate-level dimension data
- 5.1.8

    - Possible whole: evaluation of sonification projects is holistic, so it doesn't help fix the individual details, and evaluation is not standard, choice is sort of arbitrary
    - Assesment of good vs bad mappings in study (possible whole to improve)
- Some mappings weren't actually implemented in projects, marked by this study with an F.



    - This only looks at primary objective
    - Seems to be room for work in study of psychoacoustics with sonification, though study states this could be due to incomplete data set
- "The most popular ['synthesis tools'] were SuperCollider and PureData."

Questions/Other

The Sonification Handbook

Source citation

(Hermann, 2011)

Hermann, T., Hunt, A., & Neuhoff, J. G. (2011). *The Sonification Handbook*. Berlin: Logos Verlag.

Source type

book

Keywords

sonification

Summary

Reason for Interest

This book provides a good background on sonification, and is also good reference material.

Notes

See General Background.

Questions/Other

Fractal Music : The Mathematics Behind "Techno" Music

Source citation
(Padula, 2005)

Source type
Article

Keywords
Fractal, music, mathematics, Fourier Series

Summary
See Abstract

Reason for Interest
This is an easily accessible source (written by a teacher for teachers) which will help me understand some of the mathematics necessary for my project.

Notes
Abstract/Introduction/First section

- Article discusses The Fractal equation, Fourier's theorem, sound waves and "their basis in the sine curve" and algorithms to compose fractal music
- Visual fractals are self-similar and cool, they can be translated into numbers and equations which are in turn translated into music
    - Fractal coordinates can come from feeding a complex equation's result back into itself

Physics of Sound Waves

- sound waves are pressure waves, composed of infinite sum of sine waves

Fourier analysis/Fourier's theorem

- Fourier analysis is a way to analyze sound, backed by Fourier's theorem
    - Fourier's theorem says any waveform with period n can be expressed as an infinite sum of sine waves with frequencies that are integer multiples of the waveform's frequency*2π
    - The original/first frequency is called the fundamental frequency or first harmonic, corresponds to pitch
- Chaos theory is concerned with phenomena that are influenced in a large way by tiny differences
    - Equations arising from chaos theory were also used to produce fractal music

Fractal Music on the Internet

- References www.geocities.com/SiliconValley/Haven/4386
- Lorenz examined weather phenomena and found that small changes in places farther than the fifth decimal place can be important and cause changes, and this gave rise to chaos theory
    - His equations were explored musically by Diaz-Jerez on the website

Lorenz (CD Fractal Sounds – Volume 1)

- equations give x, y, z, coordinates which are then mapped to sound

Lorenz attractor

- The equation that gave the x, y, z coordinates came from seeming chaos, but had underlying structure

Lorenz attractor exists – an interesting proof

- Since equations are so sensitive and computers can't handle infinitely many decimals, mathematicians want proof (cited solution) that outputs of Lorenz attractor equations actually give orderly shape, and its not a symptom of rounding

Students and Techno

- FractMus and Musinum allow students make own fractal music

Integrated Curriculum Aspects

- music is useful for motivating students to be interested in math
- Largely irrelevant

Aesthetics

- Mathematical music isn't necessarily good music, but can be
    - Some composers have been working with fractal music, while some use it as a basis for musical pieces

Questions/Other

`Curve Shape and Curvature Perception Through Interactive Sonification

Source citation

(Alonso-Arevalo et al., 2012)

Alonso-Arevalo, M. A., Shelley, S., Hermes, D., Hollowood, J., Pettitt, M., Sharples, S., & Kohlrausch, A. (2012). Curve shape and curvature perception through interactive sonification. *ACM Transactions on Applied Perception, 9*(4), 1-19. doi:10.1145/2355598.2355600

Source type

Journal Article

Keywords

Curvature, interactive sonification

Summary

See Abstract

Reason for Interest

This article should help me get a feel for sonifying mathematical qualities, and I may use a similar sonification strategy to the one presented

Notes

Abstract

- approach that "uses sound to communicate geometrical data related to a virtual object"
  - Specifically surface of the object (from intro)
- Interface lets user "evaluate the quality of a 3D shape using touch, vision, and sound."
- many strategies to map "geometrical data…into sound"
- fundamental frequency used for "curve shape" or "curvature"
- two experiments, one with participants with "varied background," and other group had "a background in industrial design."
  - Success

Introduction

- CAD tools used in designing stage to prevent need of many models
  - However, seen on 2-D monitor and only interaction is (usually) through mouse and keyboard
- "SATIN project" – superset of this study – aims to develop augmented reality interface where users can "explore and modify" 3-D objects directly with touch
  - Sound will be one of the feedback devices, can be used to show "geometric properties related to the surface" which are hard to get from "touch or sight"
  - Existing whole in "the possible role of auditory modality"
- Shape and Curvature need to be sonified per the SATIN project
  - Important for aesthetics
    - E.g., continuous surface is prettier due to how light reflects off of it

SATIN System Description

- Visual Interface
  - Projector and 3-D glasses, glasses have a sensor for location, when touching haptic interface have illusion of touching visual object
- Haptic Interface
  - Cutting plane – 2-D cross section of object that is interacted with via the haptic interface

  - haptic strip – flexible strip that can morph into shapes, with limitations
    - Ends of strip allow adjustment of cutting plane, strip is sort of like a touch pad
- Only one currently built SATIN system, not portable, expensive
  - Researchers used a tablet and stylus to mimic haptic interface
    - Allowed for pressure sensitivity

Related Work And Background

- Previous studies (cited) show that sonification of images, higher-dimensional data, and surface data has been done successfully
- Other studies have done sections of this study's goal in other contexts
  - Interesting one to look at might be MANSUR, D. L., BLATTNER, M. M.,AND JOY, K. I. 1985. Sound graphs: A numerical data analysis method for the blind. J. Medical Syst. 9, 163–174.
- Previous research has developed "sonification toolkits" which allow for general sonification, but require "predefined data sets"
  - The toolkit I am (probably) using was mentioned

Sonification of Geometrical Data

- System will let user know about curve shape or curvature (prechosen which one) at "point of contact" of a geometrical object
- Curve shape is a plane curve from the cutting plane
- Curvature is reciprocal of radius of osculating circle, for function C=f(q) equation is
  - $\dfrac{\frac{d^2C}{dq^2}}{\left(1+\left(\frac{dC}{dq}\right)^2\right)^{\frac{3}{2}}}$
  - They use porcupine method (irrelevant knowledge)
- Mapping Data to Sound
  - Other studies have explored "best" way, find intuitive one makes everything easier
  - testing with experts led to the decision to map parameter of interest mapped to frequency
  - Linear changes mapped to logarithmic changes in sound
  - "kinetic module" "postprocesses generated sound" to allow intuitive relationship between interaction method and sound

Carrier Sounds and Kinetic Module

- Sounds carriers were Sinusoidal carrier, Wavetable Sampling Carrier, Physical Modeling Carrier
  - Each method of generating sound is mathematically intense, but ultimately they work to generate a note that sounds like a specific instrument or physical phenomenon and change the fundamental frequency as needed by input
- Kinetic module makes sound feedback more intuitive by postprocessing what would be played to the user
  - Previous (cited) study shows that wider range of "spectral slope" and frequencies require less effort to understand
  - Varies sound according to mathy equations and techniques to make it fit into an intuitive range of volume and pitch and sound harmonics

    - Not much use for sinusoidal carrier because its already so simplistic, so no complexities to be adjusted

Evaluation and Results

- 2 studies, one as previously described with tablet in UK, one in Italy with actual SATIN "setup and interface"
- First study
    - Allowed to explore curves on a tablet and hear sonification, then asked to pick out of four options the right curve corresponding to sonification
    - 75 total questions in random order, 15 in each of 5 sonification categories
    - two sessions, one for curve shape one for curvature, on different days
    - Measured accuracy and response time, and asked participants what sonification technique the preferred
        - Most preferred was "wavetable sampling carrier" (sounds like a cello)
    - No significant differences found between groups neither by curvature vs curve shape or by sonification technique (not even when adding the kinetic module)
        - Reveals probably fundamental frequency is what matters
        - Dedicated studies are probably better for determining whether or not it is useful to have sounds be intuitive
    - Kinetic module was supposed to help by making feedback more natural, which would help the brain process it better due to (cited) neurological processes
- Second study
    - Expert participants explored a vacuum cleaner using SATIN with sonification and had to determine minimum, maximum curvature and points of inflection
    - Stereo with one side positive curvature, one side negative
    - Questionnaire with many questions, participants found sound help them find un-seeable parts of curve shape and curvature, but was annoying and "not comfortable" "for long periods of time"
- Generally good results for both studies (from tables

Discussion and Conclusion

- Generally successful
- Restates earlier information
- Participants found mapping to frequency may be irritating if done for a long time
- Restates more info

Questions/Other

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

Source citation

Bonebright, T. L., Nees, M. A., Connerley, T. T., & McCain, G. R. (2001). Testing the effectiveness of sonified graphs for education: A programmatic research project. Georgia Institute of Technology. ---From Google Scholar

Source type

"Proceedings of the 2001 International Conference on Auditory Display, Espoo, Finland, July 29-August 1, 2001"

Journal Article?

Keywords

Education, Sonification, sonified graphs, gra

Summary

See Abstract

Reason for Interest

This source should help me develop my idea for testing the use of sonification in education, as it is similar to what I want to do

Notes

Abstract

- "Builds on results from sonification of data" and "comprehension of visual graphs"
- Do "sonified graphs" increase student "comprehension of graphed data"
- Are "stereo or monaural sonifications are most effective for graph comprehension" ?
- Do "sonified graphs with rhythm markers result in better comprehension than sonified graphs without them" ?
- Three experiments:
- "can [students] match auditory representations with the correct visual graphs"
- "can [they] comprehend graphed data sets more effectively by adding sonified components"?
- "can [they] be trained to use sonified graphs better with practice"
- "Results could" lead to new teaching practices and "teaching students with visual impairments"

Introduction

- Lots of research on visual graph comprehension, sonified graph comprehension research "is in its infancy"
  - Note to self, this is from 2001
- Some research on comprehension of certain graphs presented sonically, but "little research…investigating using sound in addition to visual displays in education"
- "project consists of three studies:
- matching visual and sonified graphs;
- comparing comprehension of visual and sonified graphs,
- …practicing the use of visual and sonified graphs"
- "emphasis on real data sets from" many "disciplines"

- Restates abstract

Study 1 – Matching Visual and Sonified Graphs

- "Results demonstrate" how intuitive "underlying assumptions" of sonifying graphs are to students and "how performance varies for stereo and monaural graphs"
- Participants
    - "54 college students with normal vision and hearing"
    - range 19 to 23, "mean age of 19.5"
    - 3 excluded because thought to be "not taking the task seriously" (everything wrong)
- Stimuli
    - "Real data sets" "taken from DASL" "were graphed using CricketGraphic and sonified using Metasynth and SoundEdit software packages."
    - "both bivariate and multivariate data sets"
        - Bivariate sonified using flute voice, multivariate using flute and bassoon, all data fell within three octaves
        - bivariate: x→time, y→frequency (monaural)
        - Multivariate: """""""" (binaural), frequencies in different ear
- Procedure
    - "3 practice trials" with "simplified graphs" then "24 test trials"
    - presented participants with sound then given 4 visuals, had to match the graph
    - Could repeat the sound, told to prioritize accuracy but also work quickly
- Results and Conclusions
    - "independent variable" "for the main analysis" was binaural or monaural sonification
    - "dependent variables collected included number of correct matches, reaction time for each choice, and number of times the sonified graphs were played"
    - "Participants were asked about" musical background, but this did not end up distinguishing groups
    - On average good results, mean of 42.3/51 correct matches for all graphs.
    - Hardest graphs to identify were 10 and 17, and they had a wide dispersion "and lacked a definite shape for the data"
        - "confused most often with other" graphs with similarly "widely dispersed data points and no easily discernable 'envelope'"
    - Based on stats given, mono graph matching was quicker, took less plays, and was more accurate than matching stereo graphs
        - Bivariate easier to match with their mono than Multivariate with their stereo
    - Generally, students had good graph matching, so this study means future research can expect people to match sonifications to visual graphs

Study 2 – Comparing Comprehension of Visual and Sonified Graphs

- "designed to assess comprehension of information presented in graphed data sets comparing visual graphs with two types of sonified graphs"
- "one type of graph is the same as was used in the previous study while the second type adds a rhythm component" for x-axis
    - "auditory referent for the listener"
- Varying levels of difficulty

- Participants
    - Similar sample
    - 3 groups: visual only, visual + sonification, visual + sonification + "rhythm markers"
- Stimuli
    - Similar to before, for rhythm markers have "a synthesized snare drum) that indicates the tick marks on the x-axis"
    - 28 graphs, 7 line bivariate, 7 scatter bivariate, 7 line multivariate, 7 scatter multivariate
    - Before seeing graph participants were given context/description
    - Then 4 questions of "vary[ing]…level of cognitive complexity"
- Procedure
    - 1.5 hour session
    - Survey
    - 4 practice trials
    - 4 trials per graph, one for each question
    - total 112 questions, "two 2-min breaks during the session to reduce fatigue"
    - Survey with difficulty, "strategies used to understand the graphs," "usefulness of…sounds"
- Possible Results and Conclusions
    - dependent variables:
        - "number of correct responses to questions for each graphs type"
        - "number of correct responses for each question type"
        - "number of correct responses for bivariate and multivariate graphs"
    - Will take into account demographics and musical experience
    - Ongoing study

Study 3 – Practicing the Use of Visual and Sonified Graphs

- How well practice works
- Similar methods to study 2, but "repeated exposure to the graphs over a period of 6 weeks." Each person only does one type of feedback
- Stimuli
    - Same as Study 2
- Proposed Procedure
    - Similar to Study 2, but hour long sessions for 6 weeks
- Possible Results and Conclusions
    - Same as Study 2
    - Hopefully practice improves performance
        - Hypothesis that "change will be greater for the two conditions with sound, since the students would not have had previous exposure to such displays"

Conclusions

- Obvious goals stated earlier
- "testing using a longitudinal design" to see/hope that practice makes improvement
- Past work is usually "one-shot studies"
- Future work to "focus on working with younger children and students with visual impariments."

Questions/Other

The paper is from 2001, so current work on the studies should be finished, but I can’t find it (I looked up the author on Research Gate). I am not sure if it was every finished?... If not, why not???

Towards Designing E-learning Materials Based on Multi Learner’s Styles

Source citation

(Deeb & Hassan, 2011)

Deeb, B., & Hassan, Z. B. (2011). Towards Designing Elearning Materials based on Multi Learners Styles. *International Journal of Computer Applications, 26*(3), 7-10. doi:10.5120/3086-4225

Source type

Journal Article

Keywords

E-learning, learner’s style(s)

Summary

See Abstract

Reason for Interest

This will help me learn about different learning styles

Notes

Abstract

- “each learner is provided at birth with a certain learning style specific to any of the three main ones, (Visual, Auditory and Kinesthetic).”
- “ideal learning style” is a varying mix
- Individual learning style is static combination (of possibly one) but not dynamic
- Goal to “prepare a courseware material that fits the dynamic learning needs of all learner styles”

Introduction

- Courses should be flexible to accommodate needs of variety of students
    - A goal of “adaptive e-learning systems” is to adjust material to be suitable to each learning style
- The (cited) learning style definition: “It is the way how learners perceive and process information in different way
    - Should recognize individual learning styles
- Many models, “one of the most important models is one” from Sarasin (cited), has “three preferred styles of learning”
    - Visual learners like to see teacher, facial expression, etc.
        - 5 Lessons to be analyzed are outlined, will be visual based
        - Teaching instruments should be visible, interactivity in drawing
    - Auditory learners learn through listening to discussions, etc.
        - Use pitch, speed, other aspects of sound in interpretation, so written word not as meaningful
        - Analyzed lessons include listening and speaking and acting
    - Kinesthetic learners learn by “touching, doing, and moving”
        - Hands-on and learn by exploring physical world
        - Analyzed lessons include experiment and activity types

Related Work

- “adaptive management system” supplements an e-learning system by “actively engaging learner in content interpretation”

- (cited) study showed existing focus "on Intelligent Tutoring System (ITS) and the Adaptive Hypermedia Systems (AHS)"
    - "General Teaching Community" makes it hard for adaptive e-learning "to become a main stream." Author wants integration with "e-learning tools and platforms"
- Existing "standard Moodle" (current e-learning system) doesn't treat individual learners differently
    - "Needs to be customized" to accommodate for Visual, Auditory, Kinesthetic learners
- Irrelevant (cited) study
- (cited) study showing why "improving the efficiency of learning through an e-learning environment, is due and challenging."
- Certain "VAK survey" used to asses learning style
    - "Proposed solution" aims to make lessons partially visual, auditory, and kinesthetic according to learner's needs instead of being only one, as most learners are a combination of VAK

Research Methodology

- Courseware will be combination of V, A, K styles based on multitude of learners
- Two stages: research existing literature, give survey that proves people are a combination of VAK to serve as a basis of how to design "courseware"
- Students given survey from Victoria Chislett, "a specialist in performance psychology," results were that some students have "strong inclination" to one style, some have mix of two styles, and (rarely) some have mix of all 3

Course Materials Design

- Material should be "presented in the three learning models" and "should be presented online in many different ways, including text, visual images, website links, video clips, audio clips, animation and flash."
- Lesson will have total of 5 Visual lessons, 5 Auditory, 5 Kinetic, but students will be given some of each (e.g. 2 visual, 1 auditory, 2 kinetic) according to the questionnaire
    - In old approaches there is a static combination

Proposed System Architecture

- largely irrelevant or redundant for my purposes

Conclusion

- VAK categories are useful, teachers should keep them in mind and teach all three kinds
- Future study will measure effectiveness of proposed system

Questions/Other

The future study might be an interesting read, but not completely necessary until the later stages of my product

SONIFICATION SANDBOX: A GRAPHICAL TOOLKIT FOR AUDITORY GRAPHS

Source citation

https://smartech.gatech.edu/handle/1853/50490 /
https://smartech.gatech.edu/handle/1853/50490?show=full

Source type

Article

Keywords

Sonification toolkit, auditory graphs

Summary

See Abstract

Reason for Interest

This is an article about a sonification software that seems like a viable option for my project

Notes

Abstract

- Java-based application that addresses need for a "multi-platform, multi-purpose toolkit for sonifying data"
- Users can "independently map several data sets to timbre, pitch, volume, and pan"
- Applications include assistive technology for blind people, education, data exploration, and experimentation with sonification

Introduction

- data is mapped to "parameters of a synthesized tone" "to create an 'auditory graph'"
- Current sonification software/applications are too niche and not widely accessible for usability or hardware reasons (or software dependencies)
- Need for software that everyday person can use

Related Work

- Built on previous work like MUSART, but focuses more on "addition of content" than focus "on addition of musical elements"
    - Also, MUSART written in "C++, Csound, Fltk, and OpenGL" but doesn't work for any platform
- Also works on top/after of Sound Grid, but more precise and "provide[s] auditory context"
- Most current literature have sonification solutions that are limited by "need for exotic hardware, support for very few platforms, domain-specific design, and limited numbers of data sets and/or parameters

Design

- "simple, user-friendly, moldable, responsive…one size fits all…open source"
- "easy sharing of auditory graphs across multiple platforms"
- Not as complex as other softwares
- Current Status
    - Stable version that can run on a platform with java
- Data Input
    - Can import from csv files which can be saved from excel workbooks
- Mappings
    - "each data set can be mapped to pitch, timbre, volume, and pan independently"

  - Also option for default values
  - Software does “linear transform” from original range to range specified by parameter max and minima
  - ability to “reverse the polarity of a mapping”
  - Only one data set mapped to time, which ends up being first available one entered
  - “checks and balances” in place to prevent bugs
  - context to act as tick marks can be added “in the form of a click track”
    - “Can be played at the mean, minimum, or maximum of a data set.”
- Playback and Output
  - “standard Play/Stop/Pause…buttons”, also “progress bar”, loop and hold buttons as well
  - export as a midi file
- Work in Progress
  - “continues to evolve”
  - some mappings have positive polarity (quicker=louder) but some have negative polarities
  - Needs to be set up by a non-blind person, hopeful future addition of accessibility for the blind
  - Data editing spreadsheet in the application itself and ability to save projects; also have a visual graph
    - This exists in the version I am using

Conclusions

- Need for widely-accessible tools to implement results of experimental studies in sonification
- This software is a step towards this goal

Questions/Other

Make Listening Safe

Source citation
http://www.who.int/pbd/deafness/activities/MLS_Brochure_English_lowres_for_web.pdf