Graphic-to-Sound Sonification for Visual and Auditory Communication Design

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ABSTRACT

I designed two sonification platforms designed for visual/auditory communication design studies and audiovisual art. The purpose of this study was to examine whether test participants can associate visuals and sound without any prior training and sonification approaches in this paper can be utilized as an interactive musical expression. The platform for the communication design study was developed first and the artistic audiovisual platform with the same sonification methodology followed next. In this paper, I introduce the (former) sonification platform designed for the image-to-sound association studies, their sonification methodologies, and present the study results. The object-oriented sonification method that I newly developed describes each shape sonically. The five image-sound association studies were conducted to see whether people can successfully associate sounds and fundamental shapes (i.e., a circle, a triangle, a square, lines, curves, and other custom shapes). Regardless of age and educational background, the correct answer rate was high.

CCS CONCEPTS

• **Human-centered computing**; • **Human computer interaction (HCI)**; • **HCI design and evaluation methods**; • **User studies**;

KEYWORDS

Sonification, Graphic Sonification, Auditory Symbol, Auditory Icon, Image-Sound Sonification

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1 INTRODUCTION

Graphic design plays a key role as a visual communication tool for all technology platforms. And techniques in traditional graphic design have evolved into a more dynamic and lively form in social media or other platforms we commonly use. For instance, in Apple music, album artwork has begun to be animated. Poster design or other graphic design expressions found in social media platforms animates in a smart phone screen just like when Flash-based web design was everywhere. Abstract geometric shapes that decorate poster design have started to move and this technique has become a trend in social media platforms; these platforms create new user experience in graphic design; this lively graphic design form was not previously possible with traditional printed media. What if sounds represent graphics in poster design? What if we can sense those visual shapes with sounds? A design researcher Dr. Michael Haverkamp emphasizes the importance of the cross-sensory design approach by saying that "Paul Klee and Wassily Kandinsky argued for correlations in painting and music . . . in spite of the fulfillment of functional requirement, the design of industrial products was mainly focused on the visual form." [1] The bouba/kiki effect (introduced in 1929 by a psychologist Wolfgang Köhler) [2] shows, we humans have functions that associate between visual and sound naturally and unconsciously regardless of a social and cultural background. Considering this fact, the bouba/kiki effect can be a compelling scientific resource that inspires sonification, specifically for the graphic-to-sound conversion before we create a blueprint for a comprehensive relationship between shapes and sounds. If graphic design can be combined with sonification in a way that can deliver shape and color information, this graphic-sound combination can possibly help visually impaired people approximately imagine or feel how the graphic design elements can be composed. Even for sighted people, combining sonification and graphic design has great potential to become a new type of artistic expression and communication, stretch the boundary of traditional graphic design or media art from a user experience perspective, and take a step further to the next evolution of graphic design and new media art methodology.

The goal of this study is to design sonification-driven audiovisual platforms that convert elementary visual shapes into sounds and to examine whether or not people can easily sense the relationship between them. This exploration is to show sonification as a potential to enhance visual communication design and create a new type of audiovisual expression tool.

2 RELATED WORK

An Auditory Visual Sensory Substitution System (AVSS) or Sensory Substitution Devices (SSDs) converts visual images into sounds and replace vision with sounds [3–7]. Meijer's vOICe [3, 8] is one of the most cited examples of AVSS, which is the most compared by the followers [6, 9–15]. The image-sound rendering of vOICe follows an x-frequency and y-time approach. Although vOICe sonifies visual information for its original purpose, it is not designed to describe particular shapes. EdgeSonic [11] is a smartphone-based visual aid that allows a touch interaction like Audiograf [16]. EdgeSonic follows the same x-time and y-frequency mapping of Meijer's vOICe,

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but unlike vOICe, EdgeSonic provides an edge detection feature to obtain contours of an image. Thus, when a user's finger touches these contours, a corresponding sound is generated. This model represents a pitch-responsive sound depending on the position of the image border pixels below the finger position. Similarly, Sanchez's sonification system [17] supports a mouse and a pen tablet input. In his system, both the movement of the pointer and the space between the shape and the pointer generate auditory feedback. Pitch, timbral character, and sound intensity vary based on curve shapes. Likewise, SATIN system [18] shows an example of how to convert curve values of a line into sound. Unlike a vOICe-type of methods, which is dealing with black pixel values and their position, Sanchez shows a way to express parametric curve value in sound. In Sanchez's system, when users explore the line with pointing tools over the pen tablet, the pitch goes up and down according to the vertical position of the line. These models have some similarities with my sonification method in terms of the use of the scanning path that follows the border of the shape.

For examples of sonification particularly designed to convey shapes, in 1994, Hollander [9] conducted experiments that show the effectiveness of the virtual auditory vector display. He used a virtual listening space that mimics an array of multiple speakers. Basically, the sound traces the edge of the shape in his study. In his experiment, the sound was given to the test participants using headphones and a participant's task was to identify auditory patterns and match the sounds with the images provided. The author used two types of sound displaying techniques. The first technique was that the sound moves quickly within a fixed shaped area in random or serial order. The fixed shaped area is analogous to the way an old electronic calculator displays numbers. The author named this technique "virtual auditory vector displays." The second displaying technique used the audio matrix which means that seven by seven virtual speaker arrays were employed and the auditory shapes are displayed onto the virtual speakers. The sound itself does not represent each visual shape as a whole. Instead, the sound comes out of a single point of a virtual position moving around a subject drawing a particular shape. It can be understood that each speaker plays a role as a pixel on a computer screen. These types of the study were also examined by Lakatos [23, 24] and Békésy [21], but Hollander reimplemented a similar test and migrated into the virtual auditory display world with a headphone. GUESS [22] expresses basic geometric figures such as square, circle, and triangle using a virtual 2D sound environment. The virtual tablet, the virtual sonic grid, and the localization technology were used. The virtual tablet method allows to navigate the sonification area with a pointing device. The virtual sonic grid is sound localization that divides the virtual sound environment into a three-by-three grid; the x-axis matches the clarinet sound and the y-axis matches the vibraphone sound. This serves as an indicator where the location is explored in the whole image. The basic principle of GUESS is similar to Hollander's study, and the shape is inferred by tracking the sound movement in headphones. A left triangle is described first by a tone ascending vertically in the right channel, then moving vertically from the top right to the bottom right, and finally moving horizontally from the bottom right to the bottom left. And for vertices, where two lines meet, GUESS creates a beep sound. When it comes to indicating vertices, this system has similarity to my sonification approach. Those sonification models are mainly about sound distribution in accordance with speaker arrays with a designated time lag. In my study, I sought to define "shape perception sonification" as how sonification can illustrate shapes with sounds specifically designed for their corresponding shapes, whereas in Hollander's, Kamel's or DREAM's study, it is processed by simply tracking the trace of a single sound source regardless of the sounds used. As Hollander already pointed this out, his study can be seen as an "auditory driven visualization" rather than "auditory shape perception."

Many sonification models in graphic-sound conversion tend to focus on how to connect colors, pixel values, or other graphic properties to sound parameters. And when used for user studies, many cases require memory training. Sound design approaches adopted in my research, which is based on natural image-sound association (like a bouba/kiki effect), are rare. In this paper, my sonification model aims to successfully characterize the relationship between foundational graphic design elements and sounds where most of the user study participants matched the sounds with the images without any prior training.

3 IMPLEMENTATION

The sonification system for the user study mainly consists of three components: image display, image scanning, and sonification. The shapes are drawn first and then those shapes feed into the scanning component in TouchDesigner. The image-related parameters are sent to Max for sonification. The data from TouchDesigner are transferred to Max via Open Sound Control (OSC) [23]. The research questionnaires (i.e., pre-questionnaires, task-questionnaires, and post- questionnaires) were implemented via an online research/survey tool Qualtrics [24]; the sonification sounds and their corresponding videos/still images were exported from TouchDesigner and Max, and directly shown on Qualtrics.

4 USER STUDY

4.1 Procedure

The user study was open to anyone in Virginia Tech and recruited 30 participants in total. After the appointment was scheduled, the test was held over Zoom and the study questionnaires was provided via Qualtrics online. No explanation of the sound design was provided and no pre-training was given prior to the study.

4.2 Study 1: Task and Sound Design

Study1 is designed to support my first research goal that basic waveforms (e.g., sine, triangle, and pulse) can be used to represent the characteristic of four fundamental visual shapes (a circle, a triangle, a square, and a line). The four sounds are designed by mixing two identical waveforms (with a different pitch setting) instead of using a single waveform. This is to create richer frequency components due to the drawback of a sine wave, which has only one frequency component. I found that combining two waveforms could help in describing and emphasizing each soundwave's character (e.g., rough, rounded, and edged) better. For the triangle, the square, and the line, they were also composed of a combination of two corresponding sound waves (i.e., two sawtooth waves and two pulse waves). For Study 1, a total of four images (Figure 1) and four sounds that correspond to each image are prepared. Each question

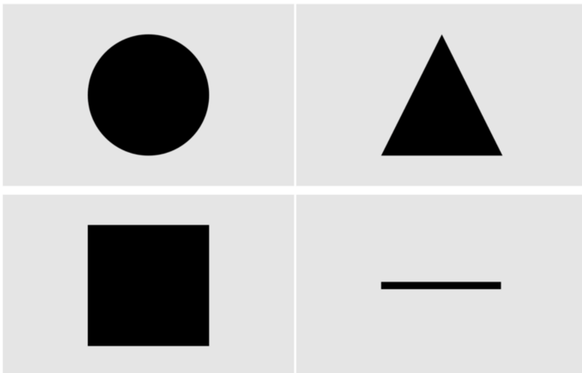

Figure 1: Four Shapes for Study 1

displays one image and four sounds (i.e., Sound A, Sound B, Sound C, Sound D). Sound A, Sound B, Sound C, and Sound D are the sounds for the circle, the line, the triangle, and the square in order. Participants first saw the image, listened to all four sounds, and then chose the answer.

The frequency of the main oscillator (the left column of each waveform) is middle C (C4) (Table 1). Each shape has an additional waveform that acts as a sub oscillator. The circle is designed to give a mellow, warm, and soft feeling by adding C3 (an octave lower), and the triangle also adds C3 (an octave lower) to emphasize its harsh and rough feeling of a sawtooth wave; the lower the frequency, the clearer the sound character between the waveshapes; in contrast, for example, the higher the frequency, the more difficult it is to distinguish between a sawtooth and a pulse wave. For the square shape, C2 (two octaves lower) is added instead of C3, to make a clearer distinction from the triangle. The sound design for the line was approached to give the feeling of a very thin rectangle by adding C5 (an octave higher).

4.3 Result: Study 1

The answer to the first question of Study 1 is Sound A (the circle). 26 participants selected the correct answer (86.67%). The answer to the second question is Sound C (the triangle). 14 participants selected the correct answer (46.67%). The answer to the third question is Sound D (the square). 16 participants selected the correct answer (40.00%). The answer to the fourth question is Sound B (the line). 13 participants selected the correct answer (43.33%). The accuracy rate for the triangle, the square, and the line were somewhat less accurate than the circle. This is probably because the sawtooth and the square wave are more complex (in terms of their overtones) than the circle, which only has two sine waves (two frequency components). The difference is that a sawtooth wave consists of frequency multiples (overtones) of the fundamental frequency and a square wave can be made similarly but it only has odd numbered partials. Although the correct answer rates for questions 2, 3, and 4 decreased, most participants picked the correct answer.

4.4 Study2 and Study3: Task and Sound Design

Study 2 and Study 3 are designed to support my second research goal that sound modulation (e.g., amplitude, pitch, filter, etc.) driven from the border of the shapes can be used to describe fundamental shapes (e.g., a circle, a triangle, a square, and lines) in more detail and can be extended to describing more complex shapes (e.g., dashed lines, curved lines, and other customized shapes). The focus of the second user study is the application of sound modulation along the edges of the shapes. The tonal character (timbre) of the shapes in Study 2 is the same as in Study 1, but the key is that x-y coordinates of the border of each shape modulate the sound to describe the shapes more clearly. I ran a brief pilot test with the four modulation types (i.e., pitch-only, amplitude-only, filter-only, and all three combined) and interestingly, the participants felt the strongest sound change when all three types were combined. Filter modulation controls the center frequency, the filter gain, the initial Q-value, and the movement of the Q-value (see Table 3 for more information). The different types of filters were applied to each shape because filter types can affect the overall tonal character for each shape, giving the sound of warm, round, rough, or sharp, for example. The amp modulation was also adjusted to the limit where all the sound could be heard as much as possible because when the wet level of the amp modulation reaches 100%, this will result in significant volume loss. The other modulation parameters have slightly different settings according to the shapes, but this different setting is to fine-tune the sound to describe each shape more effectively.

Study 2 gives a total of three images (Figure 2) and three sounds that correspond to each image. Each question displays one image and three sounds (i.e., Sound A, Sound B, Sound C). Sound A, Sound B, and Sound C are the sounds for the triangle, the circle, and the square, in order. Participants first saw the image, listened to all three sounds, and then chose the answer. Table 2 below shows the sound-shape mapping of each basic shape in Study 2.

The questions in Study 3 were given a total of 4 images (Figure 3) and 4 sounds that correspond to each image. Each question displays one image and four sounds (i.e., Sound A, Sound B, Sound C, and Sound D). Sound A, Sound B, Sound C, and Sound D are the sounds for the sine curve, the dashed line, the sawtooth line, and the pulse wave line in order. Table 2 above shows the sound-shape mapping of each basic shape in Study 3.

Table 1: Sound-Shape Mapping in Study 1

Shapes	**Circle**		**Triangle**		**Square**		**Line**	
Waveforms	Sine	Sine	Saw	Saw	Pulse	Pulse	Pulse	Pulse
Frequency (Hz)	261.6	130.8	261.6	130.8	261.6	65.41	261.6	523.3
Mix (%)	60	40	70	30	60	40	60	40
Pulse Width	N/A	N/A	N/A	N/A	0.5	0.3	0.1	0.2

Figure 2: Three Shapes for Study 2

Table 2: Sound-Shape Mapping in Study 2 and Study 3

Shapes	Circle	Triangle	Square	Line (Sine)	Line (Saw)	Line (Pulse)	Line (Dotted)
Filter Number	1 LPF[1]	1 HPF[2] 1 Peak[3]	4 Peak	1 HPF	1 HPF	1 HPF 1 Peak	NA
Filter Gain	1	HPF: 1.5 Peak: 2	2	1	1	HPF: 0.5 Peak: 2	N/A
Cutoff Frequency Range (Hz)	-100 - 100	-100 – 100	-130 - 130	N/A	N/A	N/A	N/A
Q-Value	1	1.5	2	1.5	1	HPF: 1 Peak: 0	N/A
Q-Value Sweep	-0.3 to 0.3	HPF: 1.3 Peak: 2	3	0.3	1.2	HPF: 1 Peak: 2	N/A
Amp Mod (Dry/Wet)	80/20	50/50	80/20	50/50	50/50	50/50	N/A
Amp Mod Range	-0.5-0.5	-0.5-0.5	-0.5-0.5	-0.5-0.5	-0.5-0.5	-0.5-0.5	N/A
Pitch Mod Range	0-20 cents	0-40 cents	0-50 cents	N/A	N/A	N/A	N/A

[1]Low-Pass Filter, [2]High-Pass Filter, [3]Peak Notch Filter

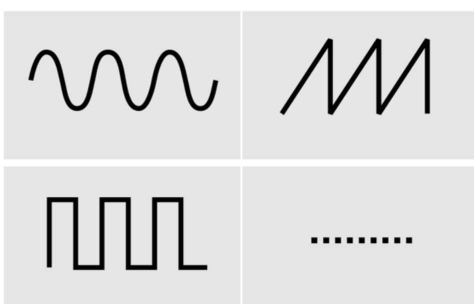

Figure 3: Four Shapes for Study 3

4.5 Result: Study 2 and Study 3

The answer to the first question of Study 2 is Sound B (the circle). 22 participants selected the correct answer (73.33%). The answer to the second question 2 is Sound A (the triangle). 23 participants selected the correct answer (76.67%). The answer to the third question is Sound C (the square). 21 participants selected the correct answer (70.00%). The answer to the first question of Study 3 is Sound A (the sine curve). 28 participants selected the correct answer (93.33%). The answer to the second question is Sound C (the sawtooth curve). 26 participants selected the correct answer (73.33%). The answer to the third question is Sound D (the pulse curve). 16 participants selected the correct answer (53.33%). The answer to the fourth question is Sound B (the dashed line). 30 participants selected the correct answer (100.00%). The result shows that the sound modulation describes the sounds of the shapes more accurately. However, the accuracy rate of the third question of Study 3 is somewhat less accurate than the others. The similarity of the sound pattern between the pulse line and the sawtooth line may cause confusion to the participants.

4.6 Study 4: Task and Sound Design

Study 4 follows the same sonification mapping except the visual shapes. Study 4 gives a total of three customized images (Figure 4) and three sounds that correspond to each image. Each question has one image and three sounds (i.e., Sound A, Sound B, and Sound C). Sound A, Sound B, and Sound C are the sounds for the star-like shape, the cloud-like shape, and the reversed stair-like shape in order. The timbre of each shape is succeeded from Study 1 and the modulation for each shape is succeeded from Study 2. That is, the star-like shape uses the same timbre and modulation from the triangle, the cloud-like shape uses the same timbre and modulation from the circle, and the reversed stair shape uses the same timbre and modulation from the square in the previous studies. Participants first saw the image, listened to all three sounds, and then chose the answer.

4.7 Result: Study 4

The answer to the first question of Study 4 is Sound B (the cloud). 30 participants selected the correct answer (100.00%). The answer to the second question is Sound A (the spike). 27 participants selected

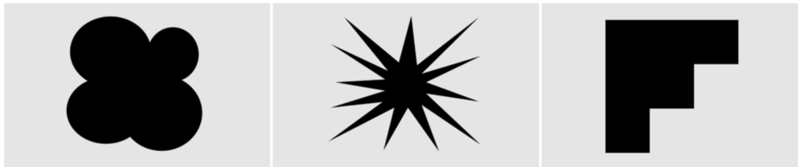

Figure 4: Three Shapes for Study 4

Table 3: Summary of significance level tests for all studies

	Study 1	Study 2	Study 3	Study 4	Study 5
A[1]	5.7809778 (0.2161)	7.9443903 **(0.0472)**	1.7655926 (0.7788)	0.2330511 (0.8900)	0. 5528657 (0.9071)
M[2]	5.4774517 (0.2417)	5.4974039 (0.2400)	4.5181965 (0.3404)	0.5503918 (0.7594)	1.4143782 (0.9227)
V[3]	4.039838 (0.4006)	6.1248589 **(0.0468)**	3.1602069 (0.3676)	1.4021033 (0.4961)	1.0023625 (0.9094)

[1]Age, [2]Music, [3]Visual Arts

the correct answer (90.00%). The answer to the third question is Sound C (the reversed stair). 25 participants selected the correct answer (83.33%). The accuracy of Study 4 is very high compared to the others. This shows that the sound modulation can be successfully applied to other customized shapes. To sum up, the result of Study 1 showed the limitations of the sound without modulation, however, other studies show that it is possible to describe different types of lines and other free-form shapes when using the sound modulation.

4.8 Probability

The questions about age and educational background were given in the pre-questionnaire test (multiple choice type), so I wanted to examine if these additional variables affect the test result. Table 3 shows the significance level based on age and educational background. I set the significance level α to 0.05 in this test ($p < .05$). JMP Pro 16 [25] was used for this statistical analysis with the logistic regression model. Entries are ChiSq (p-value). As shown in Table 5, most studies were not affected by the categorical variables. Only age and visual art background were significant for Study 2. These results clearly show that this sonification can be used as a universal auditory symbol.

5 CONCLUSION AND FUTURE WORK

The user studies mentioned above showed that a proper combination of basic waveshapes with the sound modulation, based on the border of the shape, can describe basic shapes as well as even more complex shapes such as the spiky shape, stair shape, and cloud shape. Further, the study result showed the possibility to expand for more complex shapes for future research. Considering other sound synthesis methods available, the possibilities for their applications to broader and more detailed communication design research are limitless.

Future work can be divided into two main directions. The first is the same context as the user study in this paper. As the post-questionnaire shows, my sonification approach can be used for communication design for human-machine interface. The second direction is for musical instruments with the same sonification methodology with the user study version; the artistic sonification version has already been made and will be introduced in another paper soon. Since color variables are excluded from the user test, the use of colors can be considered in the future research direction. Color-sound sonification studies necessarily require a long pre-test session to allow participants to memorize the relationship between color and sound. In fact, long pre-training sessions are a very counterproductive process. For research not to depend on memorization, better sonification strategies to reduce time for the pre-test need to be considered. Alternatively, it will be necessary to carefully consider whether a color-related study can be designed without pre-tests by applying psychological color associations.

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