BIRDSONGIFICATION: CONTEXTUAL AND COMPLEMENTARY SONIFICATION FOR BIOLOGY VISUALIZATION

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ABSTRACT

Choosing whether to represent data in an abstract or concrete manner through sonification is generally dependent on the applicability of the dataset and personal preference of the designer. For supporting a visualization with a high level of abstraction, a sonification can purposefully act as a complement by giving concrete contextual cues to the data representation with the use of auditory icons. This paper presents a case study of using bird songs as auditory icons to give context to a biology visualization, and explores how additional information of the bird species can be conveyed together with the auditory icons with parameter mapping sonification. The auditory icons are used as a foundation to convey additional information of the dataset, either by creating a parametric auditory icon, or by adding an additional sonification that accompanies the auditory icon. A user evaluation was conducted to validate and compare the different sonification mappings. The results show that there is a subjective difference of how participants perceived the sonifications, where the participants preferred sonifications that had a concrete mapping design. The sonification approaches that are explored in this study have the potential to be applied to more general sonification designs.

1. INTRODUCTION

When designing sonifications, it is often decided by the designer whether to create an abstract sonification design or one that is more concrete and connected to the data itself [22]. This continuum of sonification designs has been defined by Vickers and Hoog [29] by using the degree of indexicality, which represents *"how strongly a sound sounds like the thing that made it"* and whether it has a direct data-to-sound mapping. A common example of this is to sonify rain data, where a designer can either map the data to the pitch of a cello instrument (an abstract mapping), or to map it to the amount of rainfall heard in a synthetic model or sound sample of rain (a concrete mapping) [22]. The choice between these approaches is influenced by the personal preference of the designer, or the applicability to the dataset [14]. An abstract design can allow for a sonification that is less dependent on the data category, which in turn allows the sonification to be used for more types of data. On the other hand, a more concrete sonification approach could be tailored for one type of data and convey an association for it, while being less applicable to other data categories.

When designing a sonification that supports a visualization, there is an added consideration of what kind of sonification design would most benefit the visualization. For a visualization with limited contextual cues and a high level of abstraction, a sonification can be purposely designed to convey the theme of the data by using a concrete sonification approach, such as using auditory icons [3]. Furthermore, using a separate perceptual modality such as the auditory to give context to the data can preserve the analytical capabilities of the visualization. This can be especially useful for visualizations that aim to act both as a science communication tool and as an analytics tool. When auditory icons have been established to provide context to the visualization, there is an opportunity to convey additional information through sonification to facilitate data exploration. This information can be integrated with the use of parametric auditory icons [11], or an additional sonification can be used to convey the information. Moreover, the parametric data could in this case be mapped in a concrete or abstract manner. To explore these approaches, a case study has been performed to give context through sound to a biology visualization that conveys information about bird species. The case study enables a concrete sonification approach that uses sounds that originate from the physical source of the data object, namely bird songs, which has the potential to make the data representation more compelling and informative for a general audience.

This study aims to explore how additional information can be conveyed with auditory icons through parameter mapping sonification to support a visualization. A collection of sonifications named *Birdsongification* was created to convey complementary information of bird species together with auditory icons of bird songs to support a biology visualization. The sonification and its mappings are demonstrated together with the visualization in a demonstration video. Furthermore, a user evaluation was conducted to validate the sonification approaches and to collect user ratings and comments on which sonification mapping would be most suitable to convey complementary information.

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2. BACKGROUND AND RELATED WORK

A Cosmic View of Life on Earth [26] is an international research project that aims to create a visualization of the Barcode of Life Dataset [23], which consists of DNA barcoding samples of individuals of different animal species. The dataset is visualized in a three-dimensional information space by using dimensionality reduction [7], where the DNA barcodes are represented as data points and are placed relative to each other depending on their genetic similarity. This creates a three-dimensional visualization that is rendered using the interactive data visualization software OpenSpace [1], and enables the user to navigate the visualization. Figure 1 shows a subset of the visualization where individuals of different bird species are represented as a bird silhouette icon, and the colors represent the 35 different order of birds of the dataset. The goal of the research project is to utilize the visualization in immersive environments both for science communication and for researchers to analyze datasets. To fulfill these two use cases, there is a need to provide more context to the data representation while still preserving the analytical capabilities of the visualization. Visual context cues such as text or images of the species could be used but potentially obscure and introduce visual clutter to the visualization. A separate perceptual modality, such as the auditory, can be used to support the visual perception to give context to the visualization. Furthermore, additional information of bird species can be conveyed through sonification to present more ways of exploring the dataset and the visualization.

Figure 1: A subset of the Cosmic View visualization. Data points shaped like bird silhouettes are placed in a three-dimensional space based on genetic similarity of bird species, and the colors display the bird orders.

2.1. Sonification Design Theory

Using bird songs to convey the identity of data objects can be defined as an auditory icon, which is a short sound that conveys information about an event, object, or action [10]. Auditory icons are most commonly used in the same way as visual icons are, namely to represent objects or events in computer interfaces. The connection that the sound an auditory icon has to the object or event it is supposed to refer to, defined as the referent, creates a set of different classifications for auditory icons [3]. Overall, it is argued that an auditory icon that has a direct relation between its sound and the referent's physical source is preferred since it can be easier to learn and remember, which is known as a nomic mapping [6]. Bird song has been used together with sonification in different ways to convey information. Hoque *et al.* [13] used natural sounds such as bird songs to convey information in line charts in an accessible manner. In ByrdBot, Coleman *et al.* [5] uses the *"probability of hearing a bird"* as a parameter of how common it is in nature, and by displaying soundscapes of different time periods it conveys the decrease in biodiversity. Lockton *et al.* [17] uses bird song to convey electricity usage in the Bird-Wattching design, and mentions that *"birdsong represents an opportunity for an unused auditory bandwidth to be exploited as a channel for information"*.

A limitation of only using bird songs of different species as auditory icons is that it can make it difficult to distinguish between the sounds, especially for an untrained listener. Therefore, the bird songs used for the auditory icons should be chosen not only by how well they represent each bird order, but also by how distinguishable they are to each other as one set according to their auditory characteristics. Enge *et al.* [8] makes the connection of an auditory icon having an identity channel through its timbre, similar to how a user can differentiate the identity of data points in visualizations by their color [19]. The combination of different melodies, rhythms, and timbre of bird songs should make it possible to distinguish between them without pre-existing knowledge, making them suitable to act as auditory icons for data objects. To facilitate identification and to minimize the perceptual ambiguity of the auditory icon [4], it should be long enough in duration to capture the variation and pauses of a bird song. Brazil and Fernström [2] mention that a more complex form of an auditory icon can act as a continuous representation rather than only being a short percussive sound, which is more commonly the case for auditory icons [3]. This would create a more natural representation of the bird orders, and increase the chances of a user being able to distinguish between several auditory icons [9].

Additional parametric information of bird species can be conveyed through parameter mapping sonification. The information can be embedded with the auditory icon by manipulating it, creating a parametric auditory icon [11]. This adds a magnitude channel together with the identity channel that already exists for the auditory icon, where the identity of the data object is conveyed through the character of the bird song, and the magnitude channel is conveyed through the manipulation of the bird song [8]. This can also be described through the embodied sonification listening model by Roddy and Bridges [24], where the sonic complex is the bird song that represents the data phenomenon (the bird order), and the sonic dimension represents the sound manipulation that conveys the parametric information. One type of manipulation is, for example, to change the playback speed of the bird song audio sample. However, this manipulation can only be done to a certain degree before the sound loses its identity and begins to sound unnatural [2]. A way to limit this effect could be to manipulate the bird song in such a way that it would be perceived as less artificial to the listener, such as applying changes that would occur more naturally. Stevens *et al.* [4] modified auditory icons to convey size, distance, and direction by manipulating pitch, reverberation, and volume. Through experiments, it was shown that three manipulations can be added while keeping the auditory icon recognizable. Out of the auditory icons that were tested, a "dog bark" was best identified after being modified, which suggest that nomic auditory icons are more suitable as parametric auditory icons. Wolf *et al.* [15] used manipulations such as playback speed to convey information, and also presented a model for how several sounds can be composited together as a soundscape for the user.

Another approach to convey parametric information is to add an additional sonification layer that is mixed together with the au-

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ditory icon to convey information. This effectively separates the identity channel and the magnitude channel to two sounds that are audible at the same time, which can allow for more bandwidth for conveying the information. A common approach such as mapping the data to the pitch of an instrument can be an efficient way of conveying the data. However, choosing an arbitrary instrument to represent the data has a risk of disrupting and masking the identity of the auditory icon. One way of limiting this effect could be to choose a sound that integrates with the auditory icon in a natural manner, such as sounds that are associated with bird songs in general. This sonification approach would make use of auditory scene analysis, where several sounds that are coming from the same direction and share a similar context can be perceived as being part of the same object [25]. A suitable type of sonification design for both of the above mentioned approaches could be to use ecological parameter techniques, which assign data to acoustically complex but ecologically simple sounds and mappings [20]. This is argued to be an effective approach, as humans are more used to listening to sound objects than individual acoustic dimensions [12]. This would also imply to use ecologically-based parameterizations that are expected from the sound object that emits it [21].

3. BIRDSONGIFICATION

Birdsongification is a collection of sonifications that conveys the identity of bird orders and their taxonomy, habitat, number of species, and average wing length (see Figure 2). The identity of each bird order is represented by a bird song from one of the species in the order (see Section 3.2). Three different sonification approaches are used to convey different types of data, which are motivated by the design theories presented in Section 2.1. To convey the categorical data of taxonomy and habitat, a categorical mapping is used that enables and disables the auditory icons according to the data category they are mapped to (see Section 3.3). Parametric information is conveyed either by manipulating the auditory icon or through the use of an additional sonification. For each of these two sonification approaches, two sonification mappings have been created to explore how the data can be conveyed in an abstract or concrete manner. The parametric auditory icon represents the number of species of each bird order, and is conveyed by either manipulating the playback speed of the auditory icon, or by adding duplicate auditory icons (see Section 3.4). The additional sonification approach represents the average wing length of species in the order, and is conveyed either by the pitch and tempo of a wind chime sound, or through the pitch and tempo of a wingbeat sound (see Section 3.5). The sonifications have been integrated with the visualization, which is described in Section 3.6. The sonifications were created using the real-time synthesis software SuperCollider [18] by using either synthesized or recorded sounds. A user evaluation that compares the mappings is presented in Section 4. The sonification mappings are demonstrated through a video that displays a selection of the evaluation stimuli[1].

3.1. Data Selection

As there are 35 orders of birds in the dataset for the visualization, it would not be feasible to try to represent all of them within the scope of this study. However, the sonification would also not be particularly useful if it only represented a small fraction of the dataset. Therefore, this study considers a selection of 16 bird orders, allowing the sonification to give an overview of the dataset that is used in the visualization. The metadata of the bird orders for this case study is the taxonomy, habitat, number of species, and average wing length of each bird order. The taxonomy data was acquired from the categories found in the clade classification of Kuhl *et al.* [16]. The rest of the metadata of the bird orders was acquired from the bird trait database called AVONET [28], which contains trait data for every bird species. The habitat for each bird order was acquired by choosing the most occurring habitat for each bird order in the database. The data for the number of species was aggregated into five ranks. The fifth rank represents the order which has more species than all of the other orders combined, namely passerines (Passeriformes). The fourth rank represents orders with species between 300-400, rank 3 represents orders with 200-300 species, rank 2 represents orders with 100-200, and rank 1 represents orders with 1-100 species. The wing length data was acquired by calculating the average wing length of the species in the bird order and setting these as individual ranks with respect to the chosen bird orders.

Bird Order	Bird Song	Taxonomy	Habitat	NrSpecies(R)	Winglength(R)
Accipitriformes	Hawk	Landbirds	Forest	251 (3)	366 (15)
Casuariiformes	Emu	Non-neoaves	Forest	4 (1)	227 (10)
Anseriformes	Duck	Non-neoaves	Wetland	169 (2)	268 (13)
Passeriformes	Blackbird	Landbirds	Forest	6411 (5)	83 (1)
Strigiformes	Owl	Landbirds	Forest	238 (3)	209 (9)
Struthioniformes	Ostrich	Non-neoaves	Forest	2 (1)	545 (16)
Piciformes	Woodpecker	Land birds	Forest	376 (4)	112 (3)
Charadriiformes	Seagull	Basal landbirds	Marine	376 (4)	200 (7)
Columbiformes	Dove	Basal landbirds	Forest	331 (4)	169 (5)
Procellariiformes	Albatross	Aquatic birds	Marine	136 (2)	263 (12)
Psittaciformes	Parrot	Land birds	Forest	373 (4)	161 (4)
Gruiformes	Crane	Basal landbirds	Wetland	165 (2)	177 (6)
Falconiformes	Falcon	Land birds	Forest	63 (1)	247 (11)
Gaviiformes	Loon	Aquatic birds	Wetland	5 (1)	318 (14)
Coraciiformes	Kookaburra	Land birds	Forest	182 (2)	105 (2)
Galliformes	Rooster	Non-neoaves	Forest	296 (3)	208 (8)

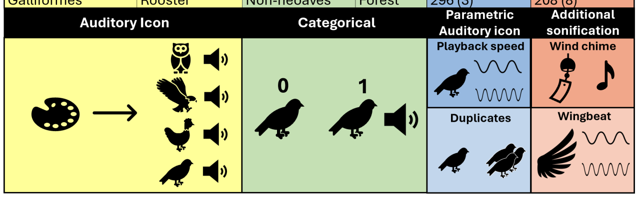

Figure 2: The 16 bird orders of the case study and their respective data categories and mappings. Values in parenthesis represents the rank of the values which is used for the sonification.

Table 1: Mapping details for the parametric auditory icons.

	Rank 1	Rank 2	Rank 3	Rank 4	Rank 5
Playback speed	0.7x	0.9x	1.1x	1.3x	1.5x
Duplicates added	0	1	2	3	4

Table 2: Mapping details for the additional sonifications.

	Rank 1	Rank 16
Wind chime pitch	C7 (2093.00 Hz)	C3 (130.81 Hz)
Wind chime tempo	1.5 Hz	0.2 Hz
Wingbeat rate	20x	1x

[1] Mapping and Evaluation Video:
https://www.youtube.com/watch?v=xjJaK6uXh-U

3.2. Auditory Icon

To identify the bird orders through sound, each of the 16 bird orders are represented with a bird song from a species that is part of the order, with an emphasis on choosing species and bird songs that are representative and recognizable. The sound selection primarily took into account to select a variety of different sounds when considering all of the auditory icons as one set. This included choosing both low and high pitched sounds, shorter and longer sounds, and sounds with different amount of sounding individuals in the sample to test the versatility of the sonification mappings. The sound sample of each bird song was up to 15 seconds, which would be repeated when presented to the user. The sound sample was chosen to be long enough to capture potential variances and pauses of the bird song, which put an emphasis on creating a realistic representation of the bird song rather than having a short sample that would be unnaturally repeated. The individual vocalizations in the sound sample could be interpreted as separate auditory icons themselves, and that the sound sample is a collection of these auditory icons. The sound selection also considered the sound to have low background noise and good audio quality, so that it could more fittingly be played together with other sounds. Loudness normalization was performed on all of the sound samples by setting them to the same loudness level (in LUFS), so that they would be perceived equally loud. The sound samples were selected from online audio libraries such as the Macauley Library and XenoCanto. The supplemental material contains a full list of the sounds and their attributions.

3.3. Categorical Mapping

The continuous auditory representation of the bird orders creates the possibility of enabling and disabling the auditory icons, which is used to convey categorical information about species. This binary mapping (turning sounds on or off) can also be used to filter the data objects, which is necessary if many data objects are intended to be represented simultaneously. For this case study, the birds are categorized based on their taxonomy and habitat. For taxonomy, the bird orders are sorted based on taxonomical groups, and for habitat, the bird orders are grouped based on the most occurring habitat in the bird order. To convey how the bird orders are categorized, the auditory icons that are part of the same category are audible together. This creates a grouping and filtering of the bird orders while conveying information about them. Furthermore, a contextual ambient sound of each habitat is played together with the auditory icons to convey the identity of each habitat. A sound recording of a forest with creaking trees represents the forest habitat, a recording of a flowing river represents the wetland habitat, and a recording of waves crashing on a shoreline represents the marine habitat (see supplemental material for sound attributions).

3.4. Parametric Auditory Icon

The parametric auditory icon approach manipulates the bird song to convey the number of species in each bird order, which has been mapped in two ways. An abstract mapping which changes the playback speed of the bird song acts as a general way to map the data. A concrete mapping which adds duplicates of the bird song sample aims to act as a more ecologically-based and natural mapping, while also reflecting the data metaphor for number of species. The mappings work in the same way across all of the auditory icons, without taking the specific sound sample into account. Both of the mappings have a positive polarity towards the data, considering that it represents an amount of objects [27].

Playback Speed: For this sonification mapping, the number of species is mapped to the playback speed of the bird song. A lower number of species corresponds to a lower playback speed of the sound, which results in a slower and lower pitched sound, and a higher number of species corresponds to a faster playback speed of the bird song, which results in a faster and higher pitched sound. The mapping was implemented by changing the playback speed of the sound in five discrete steps to represent the data (see Table 1).

Duplicates: In this sonification mapping, the number of species is mapped to how many duplicates of the bird song are heard. A lower number of species corresponds to fewer duplicates of the bird song, while a higher number of species corresponds to more duplicates of the bird song, which creates an impression of hearing more number of voices when there are more number of species. The mapping was implemented by adding versions of the same sound sample with increasing values of the data (see Table 1). Additionally, the added versions of the sound sample were shifted in starting time to not overlap with each other, and the playback rate of the added versions was modulated to create variations in pitch and tempo to mimic that different individuals are heard in the sound.

3.5. Additional Sonification

The additional sonification approach adds a sound that is played together with the auditory icon to convey the average wing length of the bird orders, which has been mapped in two ways. An abstract mapping which changes the pitch and tempo of a wind chime sound acts as a general way to map the data. A concrete mapping which changes the pitch and tempo of a wingbeat sound to convey the data aims to act as a more ecologically-based and natural mapping, considering that a wingbeat sound is commonly heard together with birds. Both of the mappings have a negative polarity towards the data, considering that it represents the size of a physical object [27].

Wind Chime: This mapping aims to offer a general approach to represent the data, so that any data could be mapped to the sound without strictly following the metaphor of the data category. However, the sound design should preferably still reflect the overall theme of the data. Therefore, a sound design inspired by a wind chime was used, which is one of the few types of instruments that is placed in nature and could be associated with birds. The data is mapped such that a shorter wing length corresponds to a higher pitch and faster onset tempo of the wind chime sound, and a longer wing length corresponds to a lower pitch and slower onset tempo of the wind chime sound. The sound consists of six sine waves to create an harmonic series of a chime sound, which fundamental pitch and tempo was changed according to the data (see Table 2), while also adding a modulation to the tempo to reflect the stochastic nature of a wind chime.

Wingbeat: For the wingbeat mapping, a sound sample of a single low-pitched wingbeat is used (see supplemental materials where the sound is listed and attributed). The playback speed of the sound sample is increased according to the data (see Table 2), such that a shorter wing length corresponds to a higher pitch and faster tempo of the wingbeat sound, and a longer wing length corresponds to a lower pitch and slower tempo of the wingbeat sound. This is perceived as hearing a low-pitched and slow wingbeat to

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represent a long wing length, and a more high-pitched and rapid succession of wingbeats to represent a short wing length. The sound is enveloped such that the sound is looped and heard for one second, and then it fades out during one second to form the impression that the bird is flying away from the listener.

3.6. Integration with Visualization

The *Birdsongification* design has been integrated with the Cosmic View visualization to explore the dataset. When the camera view in the three-dimensional space is close to the region of a bird order in the visualization, the sonification becomes louder and is panned according to where the bird order is positioned in the view. Since bird orders are only audible if they are closer to the camera view, it allows a user to filter between the bird orders by navigating to different regions of the dataset. This effectively creates an interactive and data-driven soundscape, which changes depending on where the user is located in the visualization. Each of the data mappings of the *Birdsongification* design can be individually enabled when using the visualization. With the habitat sound enabled, the type of habitat sound changes depending on what bird orders are close to the camera view. By enabling the parametric mappings, a user can explore the complementary data of the bird orders by navigating the visualization. The integration of the visualization and the sonification was implemented by sending positional data of the regions of the data from OpenSpace to SuperCollider by using the Open Sound Control protocol. A demonstration video displays a selection of the sonifications with the visualization[2].

4. USER EVALUATION

To validate and compare the sonification mappings, an evaluation was conducted which measured the user performance (accuracy and completion time) and subjective ratings when participants performed tasks using the sonifications. The evaluation tested whether a participant could distinguish between the auditory icons when several were heard at the same time when comparing their categorical data. The parametric auditory icons were tested by how well they could convey information while still preserving the characteristics of the bird song, considering that the identity and magnitude channel are combined. Lastly, the evaluation tested how well the additional sonification approach could convey the information and how fitting the sound was together with the bird song. Subjective ratings in a questionnaire included statements that compared the mappings within each sonification approach (see supplemental material for questionnaire). The questionnaire asked about the perceived confidence that the participant had when doing the tasks, which mapping was the least mentally demanding to use, which was the most pleasant, which best reflected the data category, and which mapping the participant would choose in general. Lastly, one question asked how well the parametric mapping worked with the auditory icon. For the parametric auditory icon, it was asked which mapping best preserved the characteristics of the bird song and for the additional sonification it was asked which mapping best complemented the bird song. A free-form interview captured additional opinions from the participants.

The user evaluation was performed in a closed-off room on a desktop computer setup. Two Genelec 8010A studio monitors were used to output sound, which where placed at ear level with respect to the participant, with about 40 degree angle from the center of the computer screen. The evaluation platform was created by using the SuperCollider GUI interface, where the participant selected different sounds by pressing buttons, allowing them to perform the tasks. The submitted answers and time to complete a task for each task were recorded through the evaluation platform.

4.1. Procedure

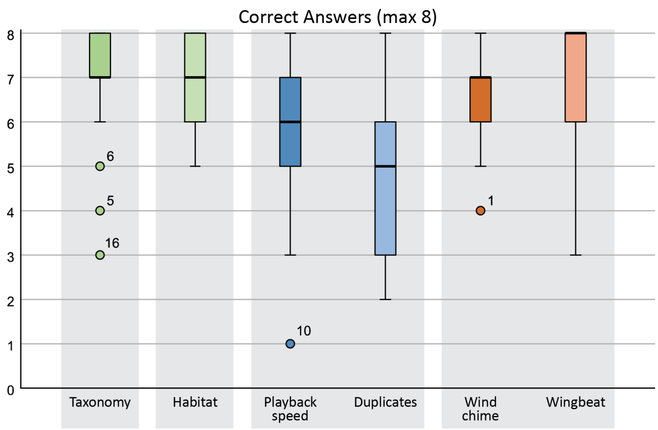
The test consisted of three sections with two parts each. Every part had an introduction and one practice example, followed by eight tasks. The stimuli used for each set of tasks were chosen such that every bird order would be used at least once. The tasks and stimuli used for the two mappings in each sonification approach were the same to create a comparable result. The test alternated between which of the mappings would be presented first for the parametric auditory icon and additional sonification to avoid any order effects. The participants was not told of the motivations of each sonification approach or mapping, only that two sonification mappings would be tested, and they were encouraged to try to answer as quickly as they could while still being confident in their answer. The evaluation took around one hour to complete.

The first section of the evaluation tested the participant's ability to acquire categorical information by distinguishing between the different auditory icons. For each task, the participant was asked to categorize a specific bird order by listening to the auditory icon of the bird order in isolation that they were assigned, and then listen to the categories that the bird order could be part of. This was performed for the taxonomy data for the first part, where the participant could choose between four categories, which were unnamed to limit any pre-existing knowledge to affect their performance. In the second part, the participant would be assigned one bird order as before, but would instead categorize it based on the three habitats that the bird orders could be part of.

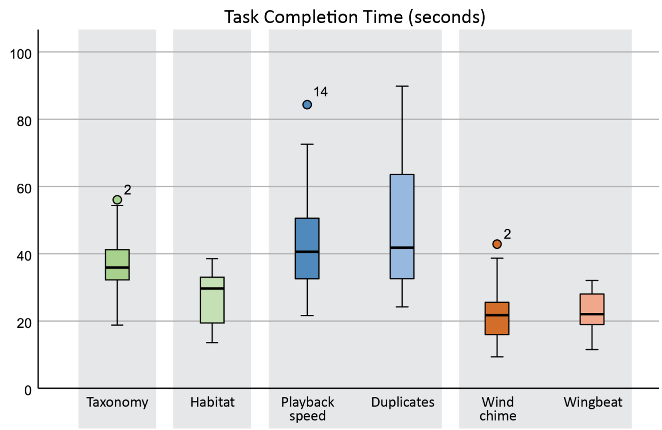
The second section tested the two parametric auditory icons to convey the number of species. The task was to determine how the number of species of the assigned bird order related to two other bird orders, and answer whether the value of the assigned bird order was the lowest, in-between, or highest compared to the other two. The participant was able to toggle the sonification to listen to the relative differences between the bird orders. For this and the next section of the evaluation, each bird song was positioned in the same way as the placement of the buttons in the evaluation platform, as an aid to distinguish between the auditory icons. Both of the sections concluded by the participant filling out a questionnaire to compare the two sonification mappings.

The third and last section tested the two mappings which used the additional sonification approach to convey the average wing length. The tasks were similar to the previous section, but instead asked whether the wing length of the assigned bird order was the shortest, in-between, or longest compared to the other two. The section concluded by giving examples of how the two additional sonification mappings would sound together with the auditory icons, and asked for the participant's opinion about which sonification mapping of wind chime and wingbeat they would prefer to use together with the bird song. Following the test were statements in the questionnaire that compared the parametric auditory icon approach and the additional sonification approach in a general sense. The evaluation concluded with a free-form interview, where the participants were able to elaborate on the ratings they had given.

[2]Demonstration Video:
`https://youtu.be/LJ1wM5ELyg8?si=Bd9Vj2hauEz7AqGD`



(a) Accuracy of the participants when performing the tasks.



(b) Average completion time of the participants when performing the tasks.

Figure 3: User performance for 21 participants out of eight tasks.

5. RESULTS

For the evaluation, 21 participants (9 female, 12 male) with an average age of 30 (range 21 to 42) were recruited among university staff and students. According to a Shapiro-Wilk test, the data was not normally distributed, therefore Wilcoxon signed-rank tests were used to analyze accuracy and completion time for the two parametric sonification approaches (*playback speed* vs *duplicates*, and *wind chime* vs *wingbeat*). Thematic analysis was performed on the free-text answers in the questionnaire and on the interview notes, which are presented together with the subjective ratings from the questionnaire in Section 5.2.

Table 3: Data for accuracy and completion time (in seconds).

	Taxonomy	Habitat	Playback s.	Duplicates	Wind c.	Wingbeat
Mean	6.86	6.76	5.67	5.00	6.76	6.86
Median	7.00	7.00	6.00	5.00	7.00	8.00
Variance	1.83	0.99	4.13	3.20	1.10	2.53
Range	5.00	3.00	7.00	6.00	4.00	5.00
MeanT	37.43	27.1	44.4	48.90	21.60	23.10
MedianT	35.87	29.69	40.62	41.83	21.73	22.06
VarianceT	77.78	67.24	275.2	408.0	72.26	33.00
RangeT	37.27	24.92	62.71	65.60	33.52	20.53

5.1. Accuracy and Completion Time

On average the participants answered 5 or more tasks out of 8 correctly for all of the sonification mappings (see Figure 3). When comparing the accuracy between the playback speed mapping and the duplicates mapping (see descriptive statistics in Table 3), there was no statistical significant difference found (Z = -1.021, p = 0.307). Regarding the accuracy between the wind chime mapping and the wingbeat mapping, there was no statistical significant difference found (Z = -0.645, p = 0.519). For task completion time, there was no statistical significant difference found between the playback speed mapping and the duplicates mapping (Z = -0.574, p = 0.566). When comparing the task completion time between the wind chime mapping and the wingbeat mapping, there was no statistical significant difference found (Z = -1.929, p = 0.054).

5.2. Subjective Ratings and Feedback

For the categorical mapping, 66% of the participants stated that they were confident or very confident when performing the tasks. All of the participants agreed or strongly agreed that the bird songs were interesting, and 76% of the participants agreed or strongly agreed that the bird songs were pleasant to listen to. 76% of the participants stated that they used their previous knowledge of birds as an aid to perform the tasks. However, two participants expressed that they used a strategy where they associated bird songs that sounded similar to belong to the same category, which caused one of them to get the lowest score for the taxonomy tasks.

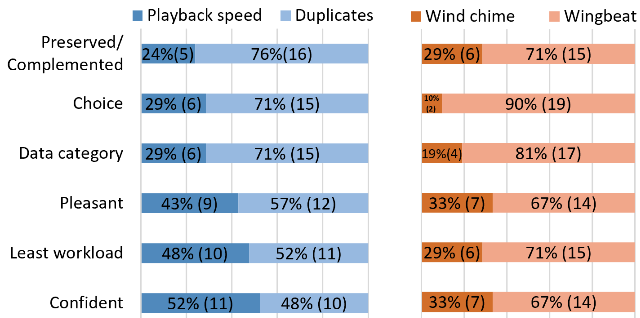


Figure 4: Preferences of the sonification mappings for the 21 participants, showing the percentages and number of answers.

The subjective ratings favor the duplicates mapping for the parametric auditory icon approach, where it received more than two thirds of the answers for every aspect except for pleasantness, workload, and confidence (see Figure 4). The duplicates mapping was expressed as more natural and organic, compared to the playback speed mapping which was perceived to be artificial in a negative manner. It was mentioned that it was in general difficult to perceive the relative difference in pitch and tempo when using either of the sonification mappings, which decreased the confidence when solving the tasks. The general strategy to use the playback speed mapping was to listen to the pitch change, while for duplicates it was to listen to the frequency or density of the sound. One participant mentioned that it was possible to quickly retrieve the value using the playback speed mapping, while it took longer time for the duplicates mapping. Another participant stated that *"if I'm told of the sonification I'll choose playback speed, if not, duplicates"*, suggesting that the duplicates mapping was easier to learn.

The subjective ratings favor the wingbeat mapping for the additional sonification approach, which got two thirds or more for all of the aspects when compared to the wind chime mapping (see Figure 4). For both mappings it was mentioned that the polarity of the mappings was challenging to learn. The general strategy to use the wingbeat mapping was to listen to the tempo of the wingbeats, while for wind chime it was to listen more to the pitch than the tempo to make a decision. One participant mentioned that they derived the value by listening to which wingbeat sounded *"heavier"*, rather than listening to a specific auditory dimension. Another participant with musical training performed better and preferred using the wind chime mapping.

The wingbeat mapping was rated to best complement the bird song (71%). Several participants mentioned that it was possible to form a mental image of the bird when using the wingbeat mapping. One participant stated that *"Wingbeat felt like having the bird in front of you"* and *"combining wingbeat with bird song strongly connect to the bird itself"*. Another participant mentioned that the wind chime and bird song conflicted more with each other since they had a more similar sound. One participant mentioned that *"If I would explore a bird atlas through sound, I would want it to be organic"*, and referred to that there are more visual abstractions in everyday life compared to auditory abstractions. In general, 66% of the participants preferred the additional sonification approach over the parametric auditory icon approach. The preferred mapping to use for data in general for the participants was 62% for wingbeat, 14% for wind chime, 14% for duplicates, and 10% for playback speed. One participant mentioned that the wind chime mapping might be more suitable for non-natural and abstract data.

6. DISCUSSION AND FUTURE WORK

The results suggest that the participants were able to solve the tasks with the sonifications, which implies that they could retrieve the intended information from the sonification mappings. The results showed no statistical significant differences in performance between the two sonification mappings for the parametric auditory icon and additional sonification approach. This suggests that both of these two approaches can be beneficially used to convey the data from an accuracy aspect. These results are promising and suggest that using concrete auditory icons together with parametric mappings to convey the identity and information of animal species can be an efficient way to convey information.

The participants could retrieve categorical information, which also proves that it was possible to distinguish between the auditory icons. This suggests that auditory icons that have a direct relation to the physical source of the data object (like the bird songs used in the present study) can be used as long as they are distinguishable from each other. A majority of the participants stated that their previous knowledge of birds helped them to categorize some of the bird orders due to their familiarity with the bird songs. However, a couple of the participants got several of the answers incorrect since they grouped bird orders that sounded similar, even though they were not part of the same category. This highlights the advantages of the familiarity with the sounds while also suggesting the disadvantages of incorrect prior knowledge when using real-world sounds to represent data objects.

In comparison to related work, this study offers a more natural representation of bird songs while also connecting them to the data of the real-life counterparts [13, 17]. However, a disadvantage of a natural representation is that it creates more variations within each bird song, which can make it more difficult to compare with others. This was apparent in the evaluation results for the duplicates mapping, which relied more on the uniformity of the sound. In these cases a more consistent approach such as the one presented by Hoque et al. [13] can provide a clearer channel of information. In comparison with other evaluations of parametric auditory icons [4], the present study also tested how well participants' think the mappings reflect the data category.

The results show that a parametric sonification can be used together with an auditory icon to convey information. The wingbeat mapping was rated as a better complement to the bird song, which could be because they were perceived to be better integrated with each other, where the participants mentioned that they could form a mental image of a bird through this approach. This highlights the benefits for presenting the identity and magnitude of a data object through two dedicated sounds that originate from the data object. Furthermore, while the sonification approaches were not evaluated together, they could be used in combination to convey multi-variate data. Future work should explore representing multivariate data about a single data object through a composition of sonifications that share an ecological connection with the data object. This should be applied to other categories and domains of data to test the versatility of the approach.

The presented sonification mappings have the potential to be used together with a visualization to facilitate exploratory data analysis, as demonstrated in Section 3.6. This allows a user to identify the data objects and regions in the visualization, while also enabling the user to compare data values between the bird orders. Considering that the sonifications were developed to be applied to any kind of bird vocalization sound sample, it allows the sonification to be scaled up to represent all of the bird orders in the visualization. Future work should evaluate the sonification mappings when used together with the interactive visualization.

7. CONCLUSION

This study aimed to explore how additional information can be conveyed together with auditory icons through parameter mapping sonification to support a visualization. A collection of sonifications named *Birdsongification* has been presented which explores how sonification can be used to convey complementary information together with auditory icons. Evaluation results suggest that participants were able to retrieve categorical information by distinguishing between the auditory icons, and to discern parametric information through parametric auditory icons and additional sonifications. This shows promise of conveying the identity and magnitude of data objects through these types of sonification approaches. Subjective ratings showed that participants preferred the duplicates and wingbeat sonification mappings, which shows benefits of using sonifications with a concrete mapping design. The study results provide an example of how different sonification approaches can be developed towards the data object that it is meant to represent in a concrete manner, and how participants perform and rate this in comparison to an abstract approach. This could be of interest for future design processes when applying the approaches to other data categories and when combining them to convey multi-variate data.

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