VibViz: Organizing, visualizing and navigating vibration libraries*

Hasti Seifi and Kailun Zhang and Karon MacLean[1]

***Abstract*— Efforts on end-user haptics is facing a new, interesting challenge: diverse end-users' needs and tastes for vibrotactile (VT) stimuli. Providing easy and highly navigable access to a large and diverse set of vibrations is one promising, yet unexplored, solution for supporting end-users' need for customization. In this paper, we propose and examine five organization and navigation schemes for a large VT library. First, we report our design process for a library of 120 vibrations with diverse functional and affective characteristics. Second, we introduce an interactive interface, VibViz, that we designed with two goals in mind: 1) support end-user navigation of the library, 2) allow us to investigate the use and engagement of the five navigation schemes. Results of a user study on VibViz suggest that *Sensory and Emotional* organization is preferred by most users and highlight interesting variations in their navigation patterns. Finally, we discuss important features for a library navigation interface.**

I. INTRODUCTION

Due to recent proliferation of vibrotactile technology in electronic devices and applications, haptic designers are now faced with a large group of users with diverse needs and tastes. Individual differences in haptic perception and affect is experienced by most VT researchers and is an ongoing challenge in VT design. The users' diversity in vibrotactile perception and affect, when not addressed, results in users' irritation; the utility of the signals are lost, thus, they are relegated to minimal roles or disabled altogether.

The need to recognize this diversity has also come up in our past projects [17] and is an emerging theme in consumer haptics [15], [11], [3], [4]. Providing easy and highly navigable access to a large and diverse collection of VT effects is one way to recognize and address users' diversity and need for customization. Navigation of a set of vibrotactile stimuli, however, holds many challenges: Unlike visual images, vibrations are hard and slow to scan. Going through all vibrations in a large library is not only boring but also impractical, as the first few vibrations quickly numb one's tactile sense. In some cases, the users may want to choose more than one vibration, similar or contrasting, for their applications (e.g., similar but varied on urgency). Comparing and selecting from a set of vibrations, that vary on many characteristics, is a daunting task. Confused and exhausted, users will either pick the first vibration(s) at hand or give up the customization task.

The few recent vibrotactile libraries, however, provide minimal organization and navigation support for the users by grouping the vibrations according to only one scheme. Although, this approach improves the users' experience but leaves many of the above challenges unaddressed.

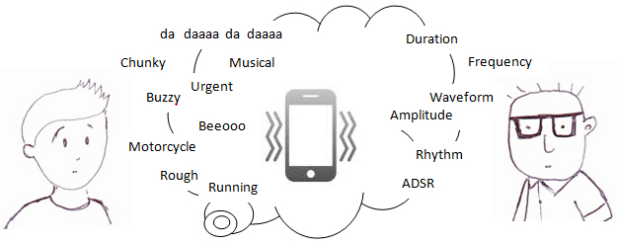

Fig. 1: Users' categorization of vibrations could be very different from engineers' categorizations.

The present research explores *how organization and representation of a VT collection can best support users in finding their desired vibrations*. Specifically, we identified five potential ways ("taxonomies") for organizing the library based on users' descriptions of vibrotactile effects in the literature. We designed a library of 120 vibrations, that varies according to those taxonomies and is large enough to require an effective organization scheme, and annotated it according to our five taxonomies. We designed VibViz, an interactive library interface, with two goals in mind: 1) support end-users, without any VT knowledge, in navigating a large VT library, 2) serve us as a research tool to investigate the effectiveness and engagement of the five VT taxonomies. Finally, we conducted a preliminary evaluation of VibViz, our library, and the five taxonomies in a user study with 12 participants where we triangulated questionnaire and observation data. Our contributions include:

- a process for creating a VT library of 120 effects
- identified challenges for large tactile libraries
- five potential organization schemes for VT effects (VT taxonomies), drawn from literature
- an interactive graphic-haptic interface for navigating a VT library (VibViz)
- a preliminary evaluation of VibViz and the five taxonomies

After related literature, we explain our process for developing the VT library and taxonomies. Section IV includes a description of VibViz interface, followed by the details of our user study. We report the results of the study on Section VI and discuss them in Section VII. Finally, we conclude and outline our future steps.

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II. RELATED WORK

A. VT Customization

Affective response to tactile stimuli is complex [8], [9] and varies by many factors including the intended application(s) [17] and individual differences in tactile perception [10], [12], [17]. This diversity in users' needs and affective response to VT stimuli calls for a better support for end-user customization of VT applications. However, relatively little has been done in this area. FeelEffects and FeelCraft, from Disney research, enable users to adjust the vibration sensation for an enhanced game play experience [11], [15]. In a past project, we investigated pros and cons of three simple authoring tools for end-user customization [16].

B. Evidence for VT Taxonomies

VT effects can vary in many dimensions and characteristics. Past studies suggested some of these dimensions to be intensity, duration, temporal onset, rhythm, and location [11], [18], [7]. Ternes and MacLean found that rhythmic vibrations can vary on their note length and evenness [18], while van Erp et al. found tempo and intrusiveness as the underlying dimensions for their 59 VT melodies [20]. Research on tactile language has suggested even more dimensions along which users perceive and interpret vibrations. Guest et al. developed a dictionary of sensory and emotional words for describing vibrations [9]. In addition, Schneider and MacLean found that people use metaphors (e.g., whistle, cat pawing) and vocalizations (e.g., bsheeeooo, tum tum tum tum) in describing vibration sensations [14].

C. VT Libraries

Haptic researchers have designed a few large collections of VT effects including Haptic Effects preview and Haptic Muse by Immersion (124 vibrations) [3], [4], Ternes' rhythmic library (84 vibrations varying on note length, rhythm, frequency, and amplitude) [18], van Erp's VT melodies (59 vibrations based on sound melodies) [20], and FeelEffects by Disney Research (over 50 vibrations for a haptic seat pad) [11]. Each of these libraries uses a unique grouping that reflects only one dimension of VT variation. For example, Ternes and MacLean structure the vibrations into five rhythm groups [18] while Haptic Muse showcases common gaming use cases of the effects (e.g, sports, casino) [4]. Here we explore the usefulness and engagement of five different VT organization schemes.

D. Visualization and Media Collections

Example systems- Research on book and media libraries suggested that visualizing these collections can provide easy and engaging access to the library and increase the chance of serendipitous discoveries [19]. The most relevant example is Musicovery, an online music streaming service, that visualizes its music collection based on mood and emotional content of the music and allows filtering by genre, date, artist, and intended activity [5]. One key difference of VT collections with the above media collections, however, is that the importance of VT dimensions is less understood compared to music or book libraries.

Visualization idioms- Our library interface uses many guidelines from Information visualization (InfoVis) domain. In the InfoVis literature, "filtering" refers to reducing the number of elements shown on the screen to a smaller subset of interest and a "glyph" can refer to any complex visual item, in contrast to single geometric primitives such as dots and squares [13]. Using multiple views and linking their content are other powerful idioms that we borrow from InfoVis. Finally, following the InfoVis guidelines, we study users' interactions with our visualization interface in a lab-based study as a first step towards a full validation of our design [13].

III. VT LIBRARY AND TAXONOMIES

Here, we present summary information about our VT library, describe our process to design the library and develop the five VT taxonomies, and report our design challenges.

A. Library Information

Our library includes 120 vibrations, large enough to require an effective organization scheme, ranging from 0.1s to 14.6s in duration and 0.05 to 0.734 in energy (measured by RMS of the signal), and is renderd by C2 actuator [2].

B. Design Process for the Library

a) First, we identified five dimensions or taxonomies along which VT characteristics can vary: 1) Physical characteristics of a vibration such as duration and energy (e.g., the vibration is about 1 second long.), 2) Sensory characteristics such as roughness (e.g, the vibration feels rough or changing.), 3) Emotional characteristics such as pleasantness, arousal and emotional words (e.g., this feels urgent.), 4) Usage Examples indicate the types of events for which a vibration can be used (e.g., this vibration is good for a reminder.), 5) Metaphors provide familiar examples that resemble the feeling of a vibration. (e.g., this vibration feels like snoring.).

b) Guided by these five initial taxonomies, we varied our design sources and experimented a lot to design unique vibrations. Specifically, we:

- collected a repository of effects from our past studies and collaborations with industry,
- systematically generated a large set of vibrations by varying the rhythm, frequency, and envelope structure,
- asked our colleagues in the HCI lab to design vibrations for a given list of metaphors (e.g., a dog, a spring, panting) with a rapid prototyping tool called mHive [14],
- designed vibrations based on iPhone's sound icons: we either used a similar timing and change in frequency or directly applied low-pass filtering to the sound icons.

In each case, we generated more variations of the existing vibrations and pruned the similar ones in an iterative process.

c) Also, we frequently annotated the resulting library according to our VT taxonomies which, in turn, led us to develop the VT taxonomies. We iterated on the a-c steps.

d) This process led to more specification of the VT taxonomies as follows:

1) *Physical* taxonomy: Properties of a vibration that can be measured. We used: 1) "Duration" of the vibration in Milliseconds, 2) "Energy" of the vibration measured by RootMeanSquare (RMS) of the signal, 3) "Tempo" or speed of the vibration (currently rated by annotators), and 4) "Rhythm structure" based on the duration of individual pulses in the vibration. We divided the vibrations into: a)"Short note rhythm", if all the individual pulses in the vibration are shorter than 0.25s, b)"Medium note rhythm", if the pulses are between 0.25s and 0.75s, c)"Long note rhythm", if the pulses are longer than 0.75s [18], d)"Varied note rhythm", if it has a combination of short, medium, and long pulses, e)"Constant", if the vibration is only one pulse.

2) *Sensory* taxonomy: 1) "Roughness", and 2) "Sensory words" from the dictionary of sensation words for touch [9].

3) *Emotional* taxonomy: 1) "Valence", 2)"Arousal", and 3) "Emotional words" from the same dictionary [9].

4) *Usage Example* taxonomy: We collected and consolidated a set of usage examples for presentation timing and exercise tracking applications based on the past research projects in our group [17].

5) *Metaphor* taxonomy: We used a questionnaire to collect a set of metaphors for our list of usage examples, asked colleagues and friends to provide metaphors for our VT effects, and used the thenounproject website [6] for brainstorming about possible metaphors. We pruned our list to a set of ⌈**FIX** *34 metaphors*⌋.

C. Design Challenges

As the library grew in size, it became more difficult to assess our progress towards our design goal (a library with diverse characteristics). Specifically, we found it very challenging to compare existing effects in the library, prune similar ones and find gaps in the library that can guide our vibration design. To track the status of our library:

1) First and for most, we made a database of existing vibrations in an excel file; each row represented one vibration. The columns indicated the vibration properties according to the five taxonomies and had filtering capability. Despite addressing our most immediate needs, this approach had several drawbacks including limited filtering functionality, slow vibration playback, lack of a visual representation for the vibration patterns to support quick visual scanning.

2) To visually inspect vibrations, we stacked subsets of (around 30) vibration waveforms in Audacity [1](Figure 2). Using this process, we could remove a few duplicate vibrations and get a better sense of vibration structures that were missing from the library.

3) Finally, we plotted the existing vibrations according to their emotional (valence and arousal) and physical characteristics (energy, duration, tempo, etc.) to get a better sense of their variations.

We realized that some of our challenges in keeping track of the library were similar to the users' challenges of using a non-structured collection of vibrations. This, in turn, lead to a first rough prototype for our library navigation interface.

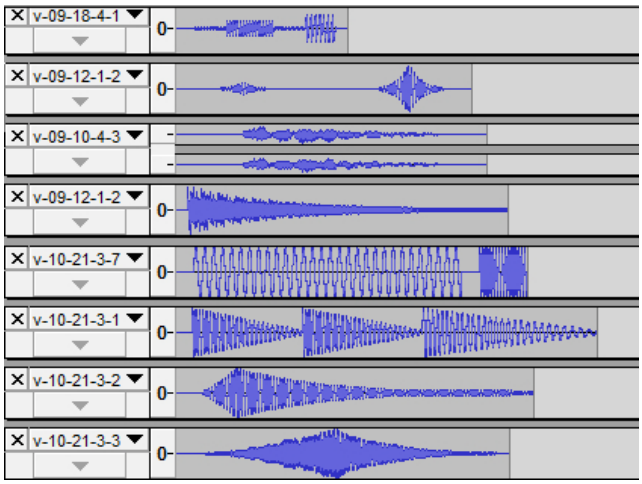


Fig. 2: Using Audacity for visual comparison of vibrations

IV. VIBVIZ: AN INTERACTVE LIBRARY NAVIGATION TOOL

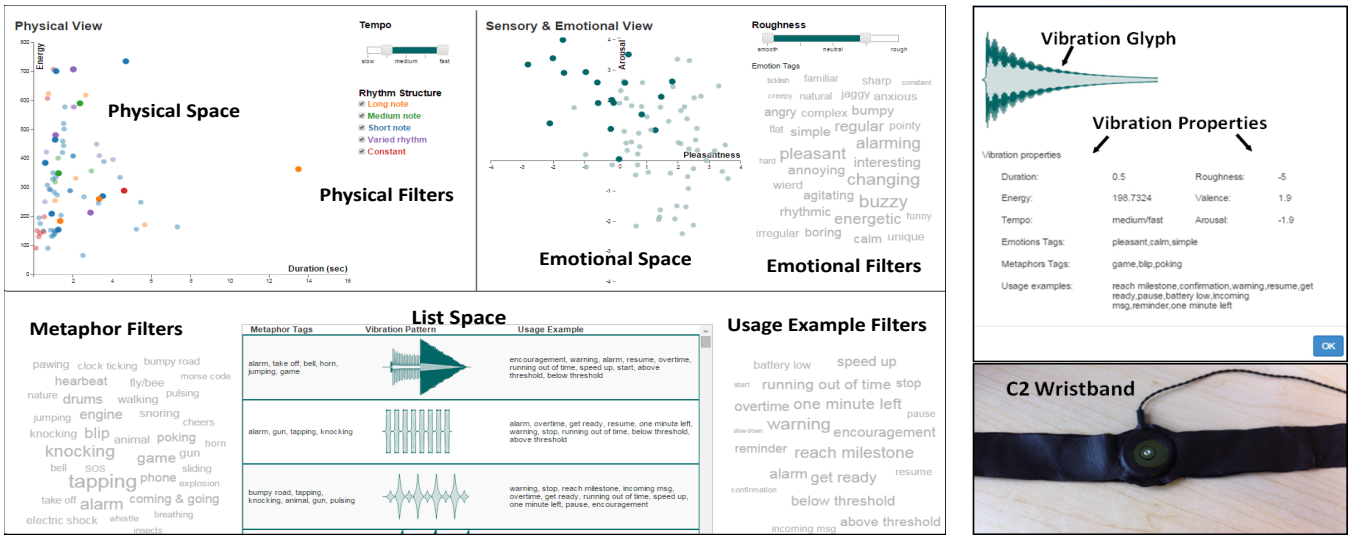
A. Requirements

We had two main goals in mind for our library interface: 1) support end-users, without any VT background, in discovering vibrations in our VT library, 2) serve as a research tool; i.e., Allow us to study usefulness of the five VT taxonomies for customization.

To support end-users, the interface must be easy to use and not require training (walkup-and-use). Also, it must support both search and exploration; we anticipated that sometimes the users would want to search based on a set of vibration characteristics in mind, while in other cases they could start exploring the library with almost no idea about their desired vibration characteristics. Further, it must support the users in discovering similar or contrasting vibrations. Finally, it should be engaging and provide multiple pathways to the library to allow for serendipitous discoveries [19]. As a research tool, it should provide a clear separation among the VT taxonomies to allow us to examine the users' interactions with each taxonomy and allow the users to effectively voice their opinions.

B. VibViz Interface

Designed based on these requirements, VibViz consists of three separate views, each with a vibration space and filters. **1) Physical view:** provides an overview of all the vibrations, each represented by a dot, according to two axes of "Energy" (vertical) and "Duration" (horizontal). This view includes three types of filters on the right side: 1) a "Tempo" range slider for filtering vibrations based on their perceptual speed, 2) "Pulse structure" checkboxes ("Short note", "Medium note", "Long note", "Varied note", "Constant"). The checkboxes have matching colors with their associated dots, and 3) horizontal zooming on the "Duration" axis. Hovering over



(a) VibViz interface- Hovering over a tag in any of the tagclouds highlights the associated vibrations on all three views.

(b) Detailed vibration popup in VibViz (top) and C2 wristband (bottom)

Fig. 3: The VibViz interface and C2 wristband that renders the vibrations

a dot in this view, shows a visual thumbnail of the vibration pattern (vibration glyph) and plays the vibration.

2) Sensory and Emotional view: We combined the sensory and emotional taxonomies because of the considerable overlap in their tags. The main part of the view plots the vibrations, each by a dot, on a 2D "Arousal" and "Valence" space. The *Sensory and Emotional* filters, on the right side, consist of a range slider for "Roughness" and a tagcloud for **Sensory and Emotional** tags. Changing the "Roughness" range or clicking on the tagcloud displays only the vibrations that have all the selected tags and their roughness level fall in the specified range. Hovering over a dot shows a vibration glyph and plays the vibration.

3) Metaphor and Usage Example view: These two taxonomies share the lower part of the screen and include a list space in the middle, a *Metaphor* tagcloud on the left and a *Usage Example* tagcloud on the right. Each row of the list shows one vibration in three columns: 1) the vibration's *Metaphor* tags, 2) its glyph, and 3) its *Usage Examples*. Hovering over the row plays the vibration. Clicking on any of the tags in the *Metaphor* or *Usage Example* tagcloud reduces the list to vibrations that have the specified tag(s).

All the three views show the same set of the vibrations at all times. This means that the result of filtering on any view is applied to all three views. Further, hovering over a vibration in any view highlights the vibration in the other views and hovering over a tag in the tagclouds highlights the associated vibrations in all three views (Figure 3a). The user can open a popup view of detailed vibration characteristics or bookmark a vibration for future reference by a left or right click respectively. The bookmarked vibrations have a highlight border in all the views.

We designed a vibration glyph to highlight the most important characteristics of a vibration's waveform and make it inspectable as a thumbnail. The glyph uses color saturation to encode the vibration frequency and a darker stroke envelope to highlight the vibration pattern over time.

C. Dataset

To import our VT library into VibViz, we needed to have all the vibrations annotated according to the five taxonomies. We measured the "Duration", "Energy" (RMS value), and "Pulse structure" for each vibration. Three researchers rated and annotated the other vibration properties; one annotated all the vibrations and each of the other two annotated half of them. We averaged the ratings and removed contradicting tags for each vibration (e.g., tag1: continuous, tag2:discontinuous).

V. USER STUDY

We ran a small user study to investigate two questions:

RQ1) Does VibViz satisfy our design requirements? (Serve as a research tool, walkup-and-use interface, support search, exploration and finding similar vibrations, facilitate serendipitous discoveries, provide multiple pathways to the library- see Section IV for details)

RQ2) How useful is each VT taxonomy for customization? How interesting is each one for end-users? Do multiple pathways to the library provide significant utility and interest over a single view of the library?

Participants and Procedure- We recruited 12 participants (7 female) using flyers and social media posts, for a 1-hour study and $10. We audio-recorded the sessions and asked the participants to verbalize their thoughts (Think-Aloud) throughout the sessions. In a pre-questionnaire, the participants wrote down 1-2 of their daily activities and their preferred notifications (e.g., activity: running, notification: start and end of each interval). Then, they explored the VibViz interface for 10 minutes on their own to get a sense of the interface and its features, while wearing a C2

tactor prototyped into a wristband (see Figure 3a-c). After that, the experimenter clarified any confusions about the interface. Then, the participants completed 9 scenarios (one at a time, 4 warm-up scenarios and 5 complex scenarios, with random ordering within each group of scenarios). Unlike the five complex scenarios that were left to the participants' interpretation, each of four warm-up scenarios could be best answered by one of the four taxonomies (see Table I). Finally, they filled a post-questionnaire. During the session, the experimenter sat beside the participant and used an observation sheet to write down confusions about the interface, any comments, and actions taken to complete each scenario.

TABLE I: Study scenarios- Green rows are warm-up scenarios, blue rows are complex scenarios.

Scenario	Description
Sc (Physical)	Find a vibration that is "short" in duration, "strong", and "fast".
Sc (Emotional)	Find a vibration that is "urgent" and "pleasant".
Sc (Metaphor)	Find a vibration that feels like a "fly or bee".
Sc (Usage Example)	Find a vibration that is good for both "start" and "stop" notifications.
Sc (Like)	Find a vibration that you like.
Sc (Not like)	Find a vibration that you do not like.
Sc (Pre-Q)	Find a vibration for the notification you wrote on the pre-questionnaire.
Sc (Combined)	Find a vibration that feels "natural", catches your attention, and is good for " "every 5 minute notification".
Sc (Similar)	Find a vibration similar to the last vibration you chose.

Data and Analysis- Our data consisted of demographics and notification types from pre-questionnaire, the experimenter's notes on confusions and list of actions for each scenario, and the ratings and comments on the post-questionnaire. During the study, we noticed that sometimes the participants used the *List*, *Physical*, or *Sensory and Emotional* spaces to explore the remaining vibrations without using the characteristics of that taxonomy. Thus, we analyzed the participants' actions on the filters and spaces separately. Due to the small size of the study and interesting variations among the participants, we mainly use summary statistics such as counts and percentages instead of running statistical tests.

VI. RESULTS

We structure this section according to our research questions.

A. RQ1) Does VibViz satisfy our design requirements?

1- Serve as a research tool for VT researchers: VibViz provided adequate separation among the taxonomy views to allow us to observe and log the participants' actions on each taxonomy. However, with the current design, automatic logging of the actions and their timing would not be meaningful and practical.

2- Walkup-and-Use for end-users: Based on the participants' comments, the meaning of the following elements were confusing during the first 10-minutes exploration: "Rhythm structure" (10 participants), "Arousal" dimension (5), "And" or "OR" operation for the filters (4). Also, none of the participants realized the ability to bookmark vibration or perform a physical zoom until they were told. 4 and 3 people did not notice linked filtering and linked highlighting of vibrations across all views, respectively.

3- Support end-users in search and exploration tasks: According to the post-questionnaire data, 9 participants followed "an explicit search" and 9 "a less-focused exploration" strategy, "many times" or "always", to find the vibrations. According to P1, *"finding vibrations always started with an explicit search up to the point that I filtered everything that I thought might not be the proper ones for the scenario. Then I explored among the available filtered options"*.

4- Support end-users in finding similar vibrations: 6 participants used the visual VT glyphs and *List* space, 4 used proximity on the *Sensory and Emotional* space and 2 used similar *Metaphor* or *Usage Example* tags for finding similar vibrations.

5- Facilitate serendipitous discoveries: Based on the definition of serendipity in [19], the frequency of finding a vibration "by accident" or "by a less-focused exploration" can be a measure of serendipitous discoveries. 8 participants found an interesting vibration "by accident", 9 found the scenario vibrations "by accident", and 11 found them "by a less-focused exploration" for at least "a few times".

6- Provide end-users with multiple pathways to the VT library: Based on the percentage of actions (see Figure 4), 7 participants used elements of at least two separate taxonomies for more than 20% of times. Also, they varied in the filter and space combinations they preferred. For example, P4 did not use the *List* space, while P9 used it frequently (62%). Finally, they used different pathways depending on the task scenario (see Figure 5).

	Filters				Spaces		
	Physical	Emotional	Metaphor	Usage Example	Physical	Emotional	List
P1	0.24	0.16	0.13	0.04	0.16	0.05	0.23
P2	0.11	0.26	0.07	0.19	0.06	0.27	0.06
P3	0.09	0.22	0.06	0.07	0	0	0.56
P4	0.19	0.23	0.09	0.12	0.09	0.28	0
P5	0.19	0.26	0.07	0.22	0.12	0.1	0.04
P6	0.16	0.26	0.11	0.07	0.04	0.21	0.14
P7	0.19	0.02	0.27	0.06	0.06	0	0.38
P8	0.17	0.25	0.09	0.03	0.08	0.1	0.27
P9	0.11	0.11	0.06	0	0.02	0.1	0.62
P10	0.11	0.32	0	0	0.13	0.3	0.13
P11	0.04	0.27	0.11	0.07	0.22	0.13	0.15
P12	0.23	0.32	0.13	0.02	0.06	0.15	0.09

Fig. 4: Average filter and space usage per participant

B. RQ2) How useful and interesting is each VT taxonomy for end-users?

Taxonomy interest and usefulness- According to the post-questionnaire data (Figure 6), the combination of all the

	Filters				Spaces		
All users	Physical	Emotional	Metaphor	Usage Example	Physical	Emotional	List
Sc(Physical)	0.57	0.09	0.02	0.02	0.21	0.07	0.04
Sc(Emotional)	0.17	0.41	0.02	0.08	0.04	0.22	0.07
Sc(Metaphor)	0.05	0.13	0.38	0	0.08	0.09	0.26
Sc(Usage Example)	0.1	0.16	0.07	0.33	0.08	0.13	0.14
Sc(Like)	0.05	0.35	0.06	0.02	0.03	0.2	0.3
Sc(Not Like)	0.05	0.3	0.02	0.05	0.03	0.23	0.33
Sc(Pre-Q)	0.19	0.13	0.08	0.07	0.18	0.05	0.3
Sc(Combined)	0.07	0.32	0.1	0.08	0.11	0.14	0.16
Sc(Similar)	0.12	0.13	0.14	0.03	0.03	0.15	0.39

Fig. 5: Average filter and space usage per scenario

taxonomies were the most interesting followed by the *Sensory and Emotional* taxonomy. *Physical* and *Usage Example* taxonomies were the least interesting to the participants. Similarly, all taxonomies were perceived useful with the combination of all and *Sensory and Emotional* being the most useful.

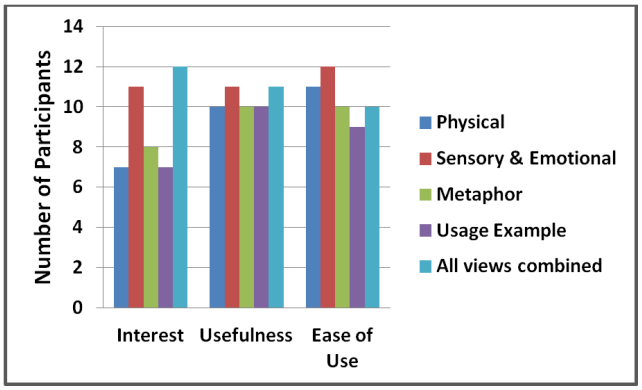


Fig. 6: Interest, usefulness, and ease of use for the VT taxonomies based on the post-questionnaire data

Frequency of taxonomy use- In response to our question of "Which of the following views would you use most often?", the majority (8) of the participants chose *Sensory and Emotional*, 3 of which wanted to have it in combination with the *Metaphor* or *Physical* taxonomies. According to P6 *"they are all useful for different things...I think I can use the metaphor and emotional view most of the time and occasionally switch to the other ones for a specific task"*. P8 had a similar comment. Among others, 3 selected *Usage Example*, and 1 *Physical* taxonomy. Our observation data matched with the post-questionnaire data in most cases. On average, *Sensory and Emotional* filters were used more (22%), followed by *Physical*(15%), *Metaphor*(9%), *Usage Example* filters(8%).

Mismatches- The post-questionnaire response from P2, P7, and P9 did not match our observation data. P2 chose *Usage Example* on the post-questionnaire but used *Sensory and Emotional* most often (26%). We think this difference was mainly due to her dislike for the tagcloud design for the *Usage Example* filters. P9 chose *Sensory and Emotional* but mostly used *List* space (62%) during the scenarios noting that *"I want to go through them all, don't wanna miss some by filtering"*. Most curiously, P7 chose *Usage Example* but used it the least during the study. Unfortunately, we cannot speculate the reason for P7's mismatch.

Other useful features- Visual VT glyphs were very useful (9 rated them as somewhat or very useful). In our observation, they were especially helpful for finding a previously seen/felt vibration, and for finding similar vibrations. According to P4, *"Based on the visual pattern, I started to realize which ones I like and don't like"*. *List* space was also used frequently (22%) for going through all the remaining vibrations. Also, P3, and P9 mainly used the *List* space for the complex scenarios since they felt that their perception of vibrations did not match some of the tags.

VII. DISCUSSION

A. Interface requirements

Based on the results, we believe the following features are important for a VT library interface: 1) filtering functionality, 2) visual vibration pattern, 3) spatial and tabular presentations, 4) bookmarking, and 5) simple VT authoring tools.

In our study, while the filters supported the search task and helped the users to narrow down to a VT subset that matched their criteria, the visual vibration glyphs, list (tabular), and spatial representations were useful for exploration. While the spatial and tabular representations allowed the users to flexibly sample the library, the visual vibration glyphs made this exploration quicker and also allowed them to find similar vibrations. In some cases, the users wanted to adjust the sensation of a vibration; this calls for incorporating simple and quick authoring tools into VT libraries [16].

B. VT taxonomies

Keep all, show a subset, allow switching- Although, the majority of the users found the combination of the taxonomies the most interesting and useful and used all the taxonomies at some point, but most often they only used about two views. Thus, we think the library navigation interface could show a subset of views to the users but allow them to switch to other views as needed. Reducing the number of views on the screen frees up the screen space for other useful functionality (e.g., a personal view for a favorite vibration subset or for temporary comparison) and makes VibViz more viable for smaller screen sizes.

Support personalization- Our results suggest that users are different in terms of which subset of the views they would prefer. Thus, supporting personalization of the default views is an important requirement. If, due to any reasons (e.g., mobile screen size), only a single taxonomy can be incorporated, our study suggests that the *Sensory and Emotional* taxonomy is a reasonable default for most users.

VIII. CONCLUSIONS AND FUTURE WORK

In this paper, we developed and studied five organization and navigation schemes (VT taxonomies) for a library of 120 vibrations. We designed VibViz, an interactive library navigation tool, to: 1) support end-users, without VT knowledge, in customizing their VT notifications, and 2) serve us as a research tool for studying the usefulness and engagement

of the five VT taxonomies. Our user study with 12 participants shows more interest in the *Sensory and Emotional* taxonomy, but also suggests interesting variations among the participants in using and preference for the taxonomies. Further, the study highlights the importance of visual scanning (tabular and spatial overview, and visual vibration pattern) for efficient navigation of VT libraries. Our next step is to collect annotations for our library from a large group of users and study variations in their opinions. In the long term, we plan to conduct a field study on end-user customization of VT applications using our library.

ACKNOWLEDGMENT

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