Sonification of Emotion in Social Media: Affect and Accessibility in Facebook Reactions

STANLEY J. CANTRELL, Sonification Lab, Georgia Institute of Technology, USA
R. MICHAEL WINTERS, Brain Music Lab & Sonification Lab, Georgia Institute of Technology, USA
PRAKRITI KAINI, Sonification Lab, Georgia Institute of Technology, USA
BRUCE N. WALKER, Sonification Lab, Georgia Institute of Technology, USA

Facebook Reactions are a collection of animated icons that enable users to share and express their emotions when interacting with Facebook content. The current design of *Facebook Reactions* utilizes visual stimuli (animated graphics and text) to convey affective information, which presents usability and accessibility barriers for visually-impaired Facebook users. In this paper, we investigate the use of sonification as a universally-accessible modality to aid in the conveyance of affect for blind and sighted social media users. We discuss the design and evaluation of 48 sonifications, leveraging *Facebook Reactions* as a conceptual framework. We conducted an online sound-matching study with 75 participants (11 blind, 64 sighted) to evaluate the performance of these sonifications. We found that sonification is an effective tool for conveying emotion for blind and sighted participants, and we highlight sonification design strategies that contribute to improved efficacy. Finally, we contextualize these findings and discuss the implications of this research with respect to HCI and the accessibility of online communities and platforms.

CCS Concepts: • **Human-centered computing → Auditory feedback**; **Social tagging systems**; **Accessibility design and evaluation methods**.

Additional Key Words and Phrases: emotion; sonification; music; accessibility; universal design; design and evaluation; social media; computer-mediated communication; affective computing

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1 INTRODUCTION

Universal design, also known as *inclusive design* or *design for all*, is a design philosophy that is concerned with the intentional design of products and systems that are accessible, usable, and useful to the broadest possible range of end-users [2, 39, 46]. Though universal design could be applied to any potential group of technology users, it is commonly used to inform the design of accessible systems for individuals living with disabilities [1, 12, 39]. Given the diverse array of human conditions, geographies, cultural contexts, sociopolitical ideologies, social and wealth inequities, etc., that exist amongst a global population [34, 42], we acknowledge that realizing a

Authors' addresses: Stanley J. Cantrell, cantrell@gatech.edu, Sonification Lab, Georgia Institute of Technology, Atlanta, Georgia, USA, 30332; R. Michael Winters, mikewinters@gatech.edu, Brain Music Lab & Sonification Lab, Georgia Institute of Technology, Atlanta, Georgia, USA, 30332; Prakriti Kaini, prakriti.kaini@gatech.edu, Sonification Lab, Georgia Institute of Technology, Atlanta, Georgia, USA, 30332; Bruce N. Walker, bruce.walker@psych.gatech.edu, Sonification Lab, Georgia Institute of Technology, Atlanta, Georgia, USA, 30332.

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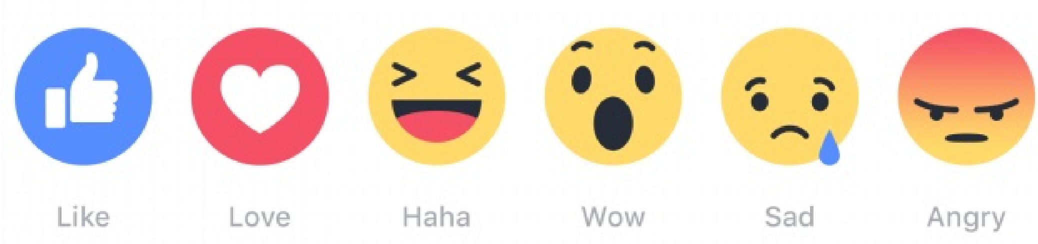

Fig. 1. The collection of Facebook Reactions. From left to right: Like, Love, Haha, Wow, Sad, and Angry.

truly *universally-accessible* [39, 44] system is highly improbable. However, the universal designer's *intent* is to permit technology access to groups that would otherwise be excluded. In the case of individuals living with **b**lindness or **v**isual **i**mpairment (BVI), *sonification*, or the use of nonspeech audio to convey information [33], is commonly used to make digital experiences accessible.

Statistics from the World Health Organization (WHO) and the National Federation of the Blind (NFB) indicate that approximately 2.2 billion people are living with visual impairment globally[1], and approximately 7.8 million people are living with visual impairment in the United States[2]. Recent studies have shown that individuals living with BVI maintain an active presence on social networking sites (SNSs), such as Facebook and Twitter, and that they engage in the same activities as their sighted counterparts [11, 38, 51, 61]. However, the user experience differs due to the inaccessibility of content and a lack of accommodations for BVI users.

The *Like button*, one of Facebook's many features, was introduced in February of 2009 and enabled users to directly interact with Facebook content, such as status updates, comments, photos, and videos. In 2016, Facebook redesigned the *Like button* and extended its functionality by integrating five new features to create what is now known collectively as *Reactions*[3]: *Like, Love, Haha, Wow, Sad,* and *Angry* (see Figure 1). The Reactions feature sought to enrich the level of interaction between users and content by broadening the range of emotions that users could share on Facebook[4]. However, while sighted Facebook users can take full advantage of this feature, the experience remains largely inaccessible to BVI users, who often use screenreaders[5] or other assistive technologies to access Facebook [8, 11]. We argue that the graphic design of *Reactions*, which utilizes visual animations and conceptual metaphors to convey affective information [63] (i.e., an animated face shedding a tear to convey sadness [17, 29]; the use of the color red to convey anger [54]), introduces cultural and accessibility barriers to the feature. Furthermore, we argue that auditory displays could aid in the conveyance of emotional constructs in computer-mediated communication (CMC) systems, thereby removing these barriers to access while also improving the usability of the feature for all users.

This paper is the first attempt to explore the design and evaluation of universally-accessible [44] sonifications to convey emotion in online CMC systems. We explore the challenge of designing and evaluating a suite of sonifications for conveying emotion, using the Facebook Reactions feature as a conceptual framework. Additionally, we provide guidelines for the design of emotional sonifications that are accessible to both sighted and BVI technology users. This study was motivated by the following research questions:

[1]https://www.who.int/health-topics/blindness-and-vision-loss
[2]https://www.nfb.org/resources/blindness-statistics
[3]https://about.fb.com/news/2016/02/reactions-now-available-globally/
[4]https://medium.com/facebook-design/reactions-not-everything-in-life-is-likable-5c403de72a3f
[5]https://www.afb.org/blindness-and-low-vision/using-technology/assistive-technology-products/screen-readers

RQ1. How effective is sonification as a means of conveying the sentiments that comprise each Facebook Reaction?

RQ2. How ought sonifications of emotion be designed such that they are distinct and easily identifiable, yet differentiable from each other?

To answer these questions, we designed 48 sonifications and conducted an online sound-matching study with 75 Facebook users (64 sighted, 11 BVI) to evaluate the efficacy of our sonification designs. The sonifications were engineered through the consultation of domain experts in music cognition, music design, and sonification theory, with the goal of incorporating the latent qualities possessed by each Facebook Reaction into our sonifications.

We note that this paper does not serve as a critique of Facebook or the Reactions feature. Rather, we've leveraged the Reactions feature as a unique research opportunity to investigate the relatively unexplored phenomena of emotion and emotional expression in online CMC systems, which we offer as the central contribution of this paper.

2 BACKGROUND AND RELATED WORK

2.1 Sonification and Emotion

Sonification is defined as "the use of nonspeech audio to convey information," and data sonification is "the transformation of data relations into perceived relations in an acoustic signal for the purposes of facilitating communication or interpretation" [5, 33, 52]. It is an interdisciplinary practice that has been employed in various accessibility and human-computer interaction (HCI) contexts. For example, sonification has been used to help users make sense of social media data [28, 43], to help make mathematical concepts accessible to students with BVI [18, 33, 52], and as an orienting stimulus in wayfinding systems for users with BVI [9, 19, 55]. Kramer et al. [33] appropriately state that: "Sonification is evolving from a field of inquiry to a field of application. The question is no longer whether it works or even whether it is useful, but rather, how one designs a successful sonification." The utility of sonification as an information aid and interaction modality is undeniable.

Though much of the academic discourse on sonification and emotion occurs outside the HCI and CSCW communities, music technology and music theory scholars have extensively investigated the use of sonification to convey emotion. At the time of this writing, Winters et al. [56–58, 60] and De Witt et al. [14, 15] provide some of the most comprehensive examinations on sonification and emotion. Both scholars situate their perspectives within music theory and music technology literature, employing principles therein to design emotional (affective) sonifications. In both cases, the seminal contributions of Juslin and Sloboda [30] and Gabrielsson and Lindström [20] provide the theoretical groundwork detailing the relationship between music and emotion, and offer best practices for eliciting specific emotions based on various factors of musical structure.

The growing popularity of SNSs has also spawned investigations into the sonification of emotion in social media. Seiça et al. [43] describe the development of a system that detects, classifies, and extracts the emotions present in a set of Twitter data, and generates a musical sonification that best represents those data. That study also highlights the cultural complexities of Western music and asserts that sonifications may not be as effective in different parts of the world. Winters et al. [58] further the discussion by proposing strategies for auditory representation of social media data. They describe, in detail, the design of an aspirational system that utilizes machine learning models and application programming interfaces (APIs) to process the information on one's feed and then to produce an auditory display to best represent that information. Within the Human-Robot Interaction (HRI) community, Yilmazyildiz et al. [62] provide a comprehensive review of non-language-based utterances used to facilitate the expression of emotion in social robots. All those studies highlight the complexities and the opportunities of sonification as a modality for conveying emotion and support the exploration of sonification and emotion in large-scale, online CMC systems where emotional exchange is increasingly prevalent but largely misunderstood.

2.2 BVI Users, Accessibility, and Social Media

The advent of SNSs has led to a transformation in the way people communicate and maintain relationships. With over 1.9 billion daily active users[6] and an Alexa ranking of 4[7], Facebook is currently the world's most popular social networking site. While Facebook and Twitter are popular choices amongst BVI users [6], SNSs that prioritize visual content, such as Snapchat, Instagram, and TikTok, are becoming increasingly popular in today's society, leaving behind a segment of BVI users who are unable to fully engage with such content. Previous studies have shown that BVI users are present on SNSs and have provided significant insights into their activities, needs, and general experiences with social networking sites [38, 51, 61].

Tigwell et al. [49] describe the many accessibility challenges that users face when using and interpreting emojis, and their negative implications for social interaction. Gleason et al. [25] describe a system capable of parsing popular memes and applying alternative-text (alt-text) and soundscapes to capture the communicative intent of the meme. Gleason extended that work by making GIFs accessible [24] with comparable efficacy. Further, Gleason provides an examination of images on Twitter and how crowdsourced alt-text descriptions have not seemed to improve the overall accessibility of Twitter [23].

Wu et al. [61] have shown that BVI users are present on SNSs and use them to communicate and collaborate with people in the very same ways as sighted users, noting that while their social networks tend to be smaller than those of sighted users, they receive more feedback on the content that they share. Voykinska et al. [51] extend those findings by demonstrating that BVI users often employ creative interaction strategies to overcome the inaccessibility of visual content on SNSs. Morris et al. [38] explored the challenges faced by BVI Twitter users, highlighting that Twitter, which was historically one of the more accessible SNSs, is becoming more inaccessible because of the increased presence of visual content. All of these studies underscore many of the shortcomings associated with the accessibility of SNSs. However, while much of the previous literature aims to improve the accessibility of SNSs for BVI users, there remains an opportunity to investigate how BVI users currently express and consume emotions on SNSs, as that specific topic remains unaddressed.

3 SONIFICATION DESIGN PROCESS

Our sonification design process was motivated by the principles of universal design [48]. To this end, we sought to produce sonifications that were useful, usable, and accessible, to the greatest extent possible, by all technology users. In this case, our target audience is broadly defined as *sighted Facebook users* and *BVI Facebook users*. Our sonification design process was informed by pilot and anecdotal data gathered during the preliminary stages of this research to design sonifications that reflect how Facebook Reactions are used in situ. By privileging this information as a starting point, we sought to orient our design thinking towards the ways that Facebook Reactions are used. For example, the Sad Reaction can be used in many contexts: as an expression of genuine sadness or disappointment, and other times in sarcastic, ironic, or joking manners. Therefore, we sought to design versatile *Sad sonifications* that would be appropriate for each of these scenarios. From this point forward, references to (visual) Facebook Reactions will appear in plain typeface (e.g., Like), and references to *sonifications* of Facebook Reactions will appear italicized (e.g. *Like*).

[6]https://www.statista.com/statistics/346167/facebook-global-dau/
[7]https://www.alexa.com/siteinfo/facebook.com

Table 1. Summary of all 48 Sonifications, grouped by Design Paradigm.

Design Paradigm	Description	Sonifications
D1	Mimicry	A1 – A6
D2	Paralanguage	A7 – A12
D3.1	Simple Music (0.5x Tempo)	A13 – A18
D3.2	Simple Music (0.75x Tempo)	A19 – A24
D3.3	Simple Music (1.5x Tempo)	A25 – A30
D3.4	Simple Music (2x Tempo)	A31 – A36
D3.5	Simple Music (1x Tempo)	A37 – A42
D3.6	Simple Music (Constant Timbre, 1x Tempo)	A43 – A48

Another guiding principle in the sonification design process was the graphic design of each Reaction. Four of the six Reactions are animated facial expressions (Haha, Wow, Sad, Angry), and the remaining two are non-facial graphics (animated thumbs-up for Like, and a beating heart for Love). These designs are simple and widely understood. We sought to replicate such characteristics in our sonification designs.

We also noted the temporal forms available in the graphic design. There exist both static (image) and dynamic (animation) forms of the Reactions. The dynamic forms cycled roughly every two seconds, similar to a GIF. In our designs, we sought to create sonifications that could be understood in the same duration of time (under two seconds). Additionally, we explored techniques that could use few notes or effects of tempo (fast vs. slow).

The sonification design process produced 8 sonifications per Reaction, resulting in a total of 48 sonifications. These sonifications were produced under three specific design paradigms and we discuss each in the following sections. Refer to Table 1 for a summary of the various design approaches.

3.1 Design 1: Mimicry

Design 1 was produced with the goal of creating sonic articulations of the movements in the existing visual animations of each Reaction. We sought to create an *expressive gesture sonification* [56] that would bring the visual Reactions into an auditory form with direct correspondence to the visual gestures (see Table 1, row D1), while also strategically utilizing musical notes that elucidated the underlying constructs of each Reaction. This design decision ensured that although sighted participants, given the visual metaphors, may be able to more readily make an association between the visual and auditory representations, BVI participants would still be able to discriminate between the 6 sonifications given the differences in salience, composition, and nuance of each sonification.

Because these sounds were short in duration and musical in nature, they closely resemble previous designs similar to *earcons* [4, 7]. By examining the animation of each Reaction as they occurred in time, we identified the exact moments of change in their gestural trajectories. For example, we coded the exact frames in the animation for the Haha Reaction when the face would transition from moving up to moving down (and reverse). In turn, these events became the *sonic generating elements*: the points in time where a sound should occur. We triggered notes at these specific moments of change. These notes are brighter (compared to *Angry* or *Sad sonifications*, for example) to further strengthen the association with the Haha Reaction.

With approximately two seconds to play a sound for each Reaction, this strategy allowed for slower, more complex designs to create the context for emotive musical cues. The resulting sounds varied in timbre, note density, note trajectory, tempo, rhythm, mode, and consonance. To determine which cues to use, we leveraged existing research from the music and emotion literature on generating sonifications of emotion [59].

Examples of Design 1 are available online[8]. Because of the clear correspondence with the visual animations, we have also provided a demo video[9] illustrating this relationship.

3.2 Design 2: Paralanguage

Having produced a collection of two-second musical sonifications linked to the animations of each Reaction in Design 1, we sought to create another design possibility for comparison. Thus, in Design 2, we set two broad goals: to make sonifications that would be easily recognizable without training, and to reduce the amount of time required to parse the sound.

Towards the first goal, we reasoned that despite the rich musical sounds used in Design 1, these sounds may still require some degree of training to be quickly recognized. Furthermore, because certain cues, such as major or minor chords, might be more culturally-specific [20], we anticipated that these cues might be more difficult to use and learn for non-Western listeners.

Towards the second goal, we reasoned that the two seconds of audio ought to correspond to the visual animation of each Reaction to further elucidate the relationship between a sonification and its intended Reaction. Although the Reaction animations looped approximately every two seconds, their static representations were also expressive and informative. For these representations, a user does not need to observe the entire dynamic animation to identify the Reaction, but can instead quickly surmise its association at a glance. Thus, we sought to design sonifications with comparable glanceability [37].

In a recent study, Cowen et al. [13] examined a collection of brief human vocalizations and found that certain vocalizations were effectively mapped onto 24 dimensions of human emotion. Given these two goals and the findings from the aforementioned study, we concluded that the use of *paralanguage* [35], specifically nonspeech vocal utterances, would be most advantageous (see Table 1, row D2).

To produce these sonifications, we recruited 2 voice actors (1 male, 1 female) to vocalize sounds that were indicative of each Reaction. The voice actors were free to utter whatever sounds they considered to be most appropriate, but were to refrain from speaking the formal name of the Reaction. We recorded the audio from these sessions and identified the best candidates for each Reaction. The results were as follows: the *Haha sonification* was the sound of laughter; *Wow* was the sound of gasping in awe or shock; *Sad* was the sound of empathetic sadness or pouting; and *Angry* was a growling, grunting sound.

The Love and Like Reactions were treated differently, as these two did not have a clear corresponding vocalization: the visual Like is a thumbs-up and the visual Love is an animated heartbeat. Therefore, similar to the visual design, we decided to leverage symbolic relationships for the sounds instead of auditory icons [22, 47]. For the *Like sonification*, we used the sound of a cash register. For *Love*, we used the sound of a heartbeat mixed with birds chirping. With these sounds, we sought to create both a relationship to the visual symbol and the underlying Reaction.

Examples of Design 2 are available online[10].

[8]https://drive.google.com/drive/folders/1U8VAmhJl9tOf-rQbMKvWuYOwluGhxPsi?usp=sharing
[9]https://drive.google.com/file/d/1rqIOLh0Ju8UGuyPqdFV2qPZWw5jo-baM/view?usp=sharing
[10]https://drive.google.com/drive/folders/1eDj3XZtBPEVF_bej5s-xiX4CUWMUm4vD?usp=sharing

3.3 Design 3: Simple Music

In Design 3, we returned to the potentials of musical sounds, but this time with simpler musical contours. The goals of this design were similar to Design 2 (speed and recognition) but were instantiated with musical sounds. These sounds would remove the association with a person's vocalization while contributing a musical quality. They were also not subject to the constraints of Designs 1 and 2: namely, mimicking the motions of the visual animations and the 2-second duration in time, respectively. But by having more relaxed time constraints, the designs would need to leverage effective emotive cues in their presentation.

The resulting sounds differed in note trajectory, pitch range, note density, rhythm, tempo, major/minor, and timbre. As in Design 1, these cues were borrowed from the music and emotion literature and, in particular, cues that would be quickly and easily comprehended. For the sake of continuity, we decided to use the same timbres as Design 1. These particular timbres had been chosen for their reinforcing quality of the desired Reaction association.

The sonifications for the two negatively-valenced Reactions (*Sad* and *Angry*) have downward pitch trajectories but differ in tempo and note density. The *Angry sonification* descends faster in pitch, more chromatically, and with more notes than the *Sad sonification*. The *Like sonification* also has a descending pitch, but the chosen musical interval is a more consonant and modally-neutral perfect 5th.

The remaining Reactions (*Haha*, *Wow*, and *Love*) all include ascending pitch trajectories but differ in note density, rhythm, tempo, and pitch range. The *Haha sonification* ascended a major 3rd and included several note strikes on the 3rd, mimicking the embodiment of an actual Haha Reaction. The *Wow sonification* was slower in tempo and included just three notes: the root, major 3rd, and octave. The *Love sonification* quickly ascended to the octave, arpeggiating all notes in a major chord along the way.

Given the significant theoretical basis of this design paradigm, we explored multiple variations of tempo (Designs 3.1 - 3.5) and a single variation of timbre (Design 3.6) to determine if a particular implementation of this design strategy performed best in practice. Because this approach was not constrained by the 2-second animation window (unlike Designs 1 and 2), we were able to experiment with sonifications that were both shorter and longer in duration. As a result, Design 3 produced 6 sub-designs: 5 tempos (0.5x, 0.75x, 1.0x, 1.5x, and 2x) and 1 timbre (1.0x). In total, this design approach produced 36 sonifications (see Table 1, rows D3.x).

Examples of Design 3 are available online[11].

4 PARTICIPANTS

Participants were recruited via university mailing lists, Facebook, GroupMe, Instagram, an internal collegiate participant pool, and snowball sampling [3]. Participants from the internal participant pool received extra credit in a course for completing the study. To better connect with individuals living with BVI, we consulted a local disability resource center to advertise our study. All BVI participants received $15 in compensation for their participation in the study. In total, we collected 75 responses: 64 from sighted participants (n_{female} = 35, n_{male} = 29; M_{age} = 20.14, SD_{age} = 2.02, $Range_{age}$: 18 − 30); and 11 from participants with BVI (n_{female} = 5, n_{male} = 6; M_{age} = 49.09, SD_{age} = 13.32, $Range_{age}$: 33 − 80). BVI participants were asked to briefly describe their level of visual impairment: 5 (45%) self-identified as *totally blind*; 6 (55%) self-identified as *low-vision*. Several researchers have demonstrated successful usability studies with small samples of BVI participants [19, 31, 32, 40].

[11] https://drive.google.com/drive/folders/1kal2dC2vT2WpQwzoEFPDmZl6E3X3CDmj?usp=sharing

Sixty-three (63) sighted participants (98%) reported using an Android phone (22%) or an iPhone (77%), whereas 9 participants with BVI (82%) reported using an Android phone (27%) or an iPhone (55%). Three participants reported that they did not own a smartphone. All participants with BVI reported using a screenreader or similar assistive technology to navigate their devices.

Sixty-one (61) sighted participants (95%) and all participants with BVI reported having an active Facebook account. Three participants reported not having an active Facebook account. All participants reported that they are familiar with the Reactions feature on Facebook.

5 PROCEDURE

We conducted an online sonification-matching study to evaluate the efficacy of each of the 48 sonifications. The sonifications were evaluated by sighted and BVI Facebook users via the Qualtrics Survey Platform. This data collection strategy was inspired by the sound-card sorting evaluation technique described by Bonebright et al. [5, 27]. This evaluation employed a within-subjects design where all participants responded to each question. At the beginning of the IRB-approved study, participants were presented with an Informed Consent form that outlined the purpose of the research study and their rights as research participants. Consent was obtained electronically by selecting *Agree* or *Disagree*. Participants who selected *Agree* progressed to the next section; participants who selected *Disagree* were directed to the end of the survey.

Participants were instructed to listen to each sonification and select the Facebook Reaction they believed best corresponds to it. Due to limitations of the Qualtrics Survey Platform, static representations of each Facebook Reaction were used in place of dynamic representations. Participants did not receive any training before the study, nor did they receive feedback on their selections. In total, participants made 48 selections. We utilized a multiple-choice, single-answer question format to allow participants to make their selections. After completing the activity, participants were directed to a brief demographics survey. At the end of the survey, participants were encouraged to e-mail the research team if they had any questions regarding the study.

Though sighted and BVI participants completed the same study, the experience was markedly different for each group. All sighted participants were able to complete the study remotely without the intervention of a researcher. This study design permitted the collection of more data, though it increased the opportunity for mischievous respondents (participants who intentionally provide false information) [41]. As such, we sought to increase our sample size for sighted individuals to reduce sampling bias. Gosling [26] describes several measures that can be taken to preserve the integrity of survey responses. All questions were randomized to minimize question order bias. Additionally, we embedded multiple attention checks to identify and eliminate responses from inattentive participants.

For BVI participants, the research team anticipated compatibility issues with screenreaders and internet browsers while completing the activity. Therefore, we required these participants to complete the study onsite at a research facility under the guidance of a researcher who would facilitate the study. The researcher read aloud the Informed Consent document and the instructions for each phase of the study, logged the participant's responses on the laboratory computer, and verbally addressed any of the participant's concerns. BVI participants were provided a set of Sennheiser HD 280 Pro headphones to offer a robust listening experience while completing the study.

At the beginning of each activity, participants were given a detailed set of instructions for completing the study. Participants listened to each sonification and selected the Reaction that they believed best corresponded to it. The sonifications appeared on the screen as interactive HTML audio players, granting participants (or the researcher) the ability to replay the sonification, increase or decrease volume, and play or pause the sonification (See Figure 2). Each sonification

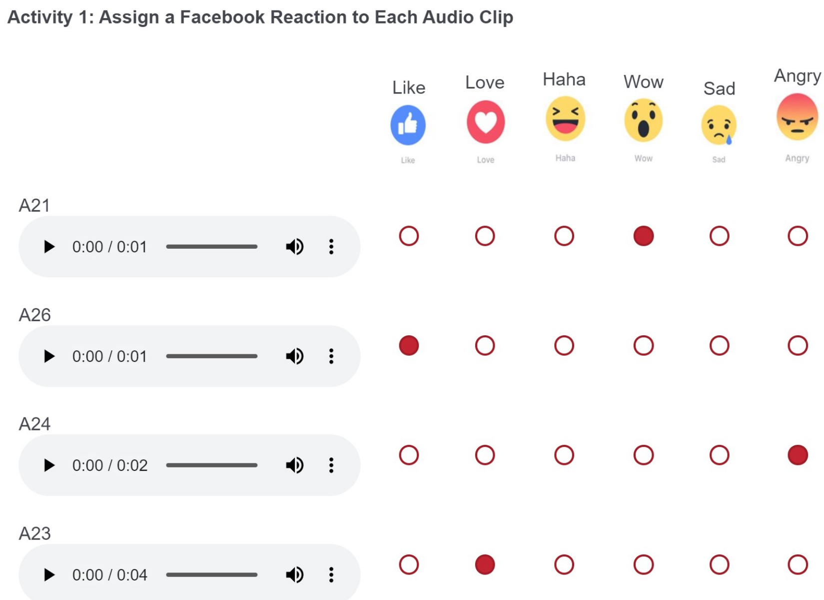

Fig. 2. A screengrab of the Qualtrics Survey tool used to conduct the sound-matching study.

was anonymized via a unique ID number to further reduce bias. Participants were required to listen to each sonification before making their selection, and they were able to replay each sonification as many times as necessary before making a selection. This process was repeated until the participant completed the activity. The Qualtrics Survey Platform recorded and anonymized all response data.

6 EVALUATION STRATEGY

Given that the goal of this study was to identify sonification design approaches and strategies that produce effective sonifications of Facebook Reactions, we opted for a quantitative evaluation methodology. This methodology allowed us to orient our analysis wholly towards the efficacy and performance of our sonifications, and then make inferences, based on these data, about the parameters and fundamentals that inspired the design of the leading sonifications. Specifically, this entailed the triangulation and contextualization of multiple sources of data to assess effectiveness: the overall distribution of selections made throughout the study; the distribution of accurate selections made throughout the study; the distribution of inaccurate selections, or confusions, made throughout the study; and the performance of individual sonifications. Additionally, this requires us to operationalize and define *effectiveness*. Given the difference in sample sizes of our BVI and Sighted groups, we chose an evaluation strategy that would allow us to consider multiple variables before making any determinations.

While many usability studies have employed qualitative techniques to evaluate sonifications and auditory displays, this is commonly done to assess user satisfaction, preferences, and opinions towards them [27, 52]. In this case, we are not yet concerned with such measures because we submit that our goal is not to propose that *these sonifications* be used on Facebook. Rather, we designed these sonifications to serve as research devices to help improve our understanding of which sound parameters, design strategies, and approaches prove to be effective, such that we can

Table 2. Sonification Effectiveness Hierarchy.

Effectiveness Tier	Accuracy Rate Range
1 (Very Effective)	91% – 100%
2	84% – 91%
3	76% – 83%
4	68% – 75%
5	59% – 67%
6	50% – 58%
7 (Ineffective)	<50%

begin to develop a framework for designing effective sonifications of emotion, within the context of online CMC systems.

We designed this study under the premise that any effective sonification, in the context of Facebook Reactions, must achieve an accuracy rate of at least 50% within at least 1 group (either BVI or Sighted) to be considered a viable candidate. We derived this metric by reasoning that an effective sonification must, at a minimum, reduce the overall solution space by half. This effectively improves the odds to that of a coin-flip, where the odds of an accurate and inaccurate selection are equal (50%). Considering that a sonification only has a 1 out 6 (16.7%) chance of an accurate association at random, this baseline metric necessitates a probability of accurate selection 3x greater than random chance. Further inspection of the sonification in question would reveal qualities that contributed to its effectiveness.

Lastly, we proposed a Sonification Effectiveness Hierarchy by which we further categorize sonifications based on their performance (see Table 2). The meaningful tiers are 1 through 6; sonifications ranking in Tier 7 are, by definition, deemed ineffective. These categories were derived by grouping the upper 50% of performers into 6 categories – 1 category for each Facebook Reaction – each with a range of 50% ÷ 6 = 8.3%. Thus, as you ascend the Sonification Effectiveness Hierarchy, sonification effectiveness increases, which increases the probability of an accurate association and reduces the probability of an inaccurate association. Sonifications that cluster towards the top of the Sonification Effectiveness Hierarchy will undergo further inspection to determine why they were effective, and which sound parameters and design strategies contributed to their effectiveness.

7 RESULTS

Each of the 75 participants responded to all 48 sonification-matching tasks. In total, we collected 3600 responses. In this section, we discuss the: 1) distribution of all selections; 2) distribution of all accurate selections; 3) distribution of inaccurate selections; and 4) sonifications that ranked in the top 50% of performance.

7.1 Distribution of Selections

We examined the overall distribution of selections made during the study. As shown in Figure 3, the Like Reaction was selected most often, while Haha was selected least often. This trend was present for both the BVI and Sighted groups. The Like and Sad Reactions accounted for approximately half of all selections, with Love, Haha, Wow, and Angry making up the remaining half. The BVI and Sighted groups accounted for 528 (14.7%) and 3072 (85.3%) selections, respectively, resulting in a total of 3600 selections.

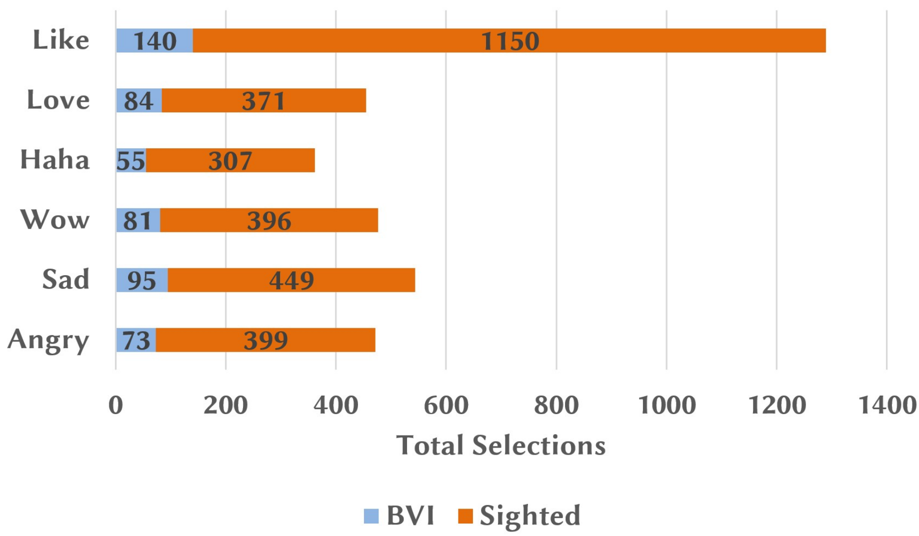

Fig. 3. Summary of all 3600 selections made by BVI and Sighted participants during the study.

A chi-square test showed a significant difference in the distribution of selections made by the BVI and Sighted groups, $\chi^2_{(5,n=3600)} = 26.0$, $p < .001$, Cramer's $V = .085$. Post-hoc analysis with Bonferroni correction (6 comparisons; $\alpha = .05/6 = .0083$) revealed that the Sighted group selected the Like Reaction significantly more often than the BVI group, $p < .0001$.

Chi-square goodness of fit (GOF) tests were performed to compare the distribution of selections made by the Sighted and BVI groups against an even distribution (16.7%). The proportion of selections differed significantly from an even distribution for the BVI group, $\chi^2_{(5,n=528)} = 47.0$, $p < .001$, and for the Sighted group, $\chi^2_{(5,n=3072)} = 974.9$, $p < .001$.

An analysis of residuals was performed to identify Reactions that were selected more or less often than their expected counts. For the BVI group, the Like and Sad Reactions were selected more often than expected, Haha and Angry were selected less often than expected, and Love and Wow selections approximated the expected counts. For the Sighted group, the Like Reaction was selected far more often than expected, and each of the 5 remaining Reactions were selected less often than expected.

7.2 Accuracy

We designed each sonification to be exclusively associated with one of the six Reactions. We examined the frequency of accurate selections (matches) made throughout the study. Figure 4 provides a summary of the accuracy rates achieved by both groups during the study. *Angry sonifications* were accurately matched most often, followed by *Like, Sad,* and *Love.* This trend was present for the BVI and Sighted groups. *Haha* and *Wow* sonifications were matched least often in all scenarios. The BVI and Sighted groups accounted for 192 and 1257 accurate associations, respectively, resulting in a grand total of 1449 (40%) accurate associations.

A chi-square test revealed that the Sighted group was slightly more accurate than the BVI group, $\chi^2_{(1,n=3600)} = 3.9$, $p = .049$, Cramer's $V = .033$. There was not a significant difference in the overall

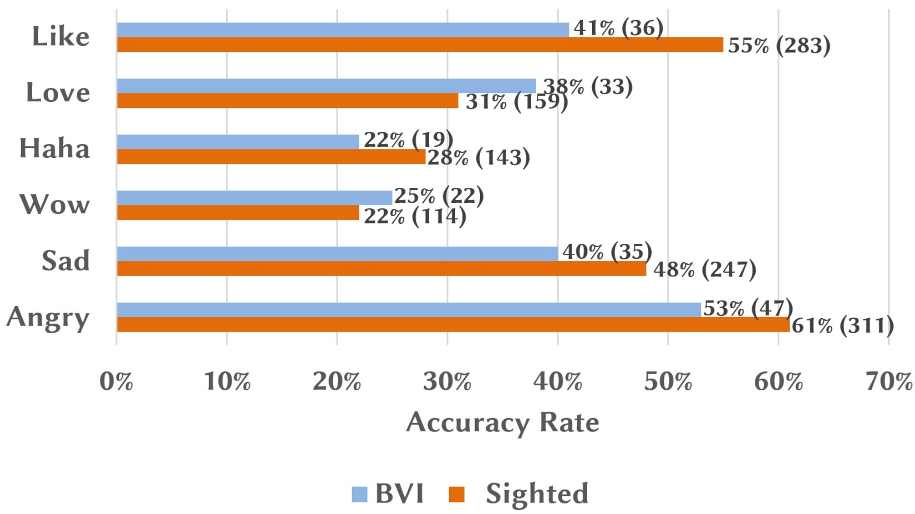

Fig. 4. Summary of accuracy rates achieved during the study. Total number of accurate associations made by each group appear in parentheses.

distribution of accurate matches made by the Sighted and BVI groups and, $\chi^2_{(5,n=1449)} = 5.18$, $p = .395$, Cramer's $V = .060$.

GOF tests were performed to compare the distribution of matches for the BVI and Sighted groups against an even distribution (1 out of 6; 16.7%). In this case, an even distribution is also the probability that an accurate selection was made at random. The distribution of accurate matches differed significantly from an even distribution for the BVI group, $\chi^2_{(5,n=192)} = 16.3$, $p = .006$, and for the Sighted group, $\chi^2_{(5,n=1257)} = 158.5$, $p < .001$.

For the BVI group, an analysis of residuals revealed that *Angry, Like, Sad,* and *Love* sonifications were matched more often than expected, whereas *Haha* and *Wow* were matched less often than expected. For the Sighted group, *Angry, Like,* and *Sad* were matched more often than expected, whereas *Wow, Haha,* and *Love* were matched less often than expected.

7.3 Inaccuracy and Confusion

We anticipated that some of our sonifications might not perform as well as intended, which could lead to an observed sonification being incorrectly associated, or *confused*, with the unintended Facebook Reaction. Indeed, there may be instances when a *confusion* is justifiable. Example permissible confusions include:

- Confusing a *Like sonification* with the Love Reaction
- Confusing a *Love sonification* with the Like Reaction
- Confusing a *Sad sonification* with the Angry Reaction
- Confusing an *Angry sonification* with the Sad Reaction

We reasoned these confusions would be permissible given the similarity of their underlying constructs. For example, if a *Love sonification* is associated with the Like Reaction, the two constructs are similar enough such that this type of confusion may have some merit. Conversely, we would not want participants to consistently associate an *Angry sonification* with Like or Love Reactions, as these constructs are considerably dissimilar.

Table 3. Confusion matrix summarizing all confusions made by the BVI group during the study. Permissible confusions appear in **bold**.

		Observed Sonification						
		Like	Love	Haha	Wow	Sad	Angry	
BVI Selections	Like		**23 (42%)**	25 (36%)	22 (33%)	27 (51%)	7 (17%)	104
	Love	**11 (21%)**		13 (19%)	19 (29%)	6 (11%)	2 (5%)	51
	Haha	11 (21%)	4 (7%)		10 (15%)	4 (8%)	7 (17%)	36
	Wow	7 (13%)	12 (22%)	19 (28%)		6 (11%)	15 (37%)	59
	Sad	23 (44%)	8 (15%)	7 (10%)	12 (18%)		**10 (24%)**	60
	Angry	0 (0%)	8 (15%)	5 (7%)	3 (5%)	**10 (19%)**		26
Total Confusions		52 (100%)	55 (100%)	69 (100%)	66 (100%)	53 (100%)	41 (100%)	336

Table 4. Confusion matrix summarizing all confusions made by the Sighted group during the study. Permissible confusions appear in **bold**.

		Observed Sonification						
		Like	Love	Haha	Wow	Sad	Angry	
Sighted Selections	Like		**243 (69%)**	259 (70%)	241 (61%)	89 (34%)	35 (17%)	867
	Love	**40 (17%)**		49 (13%)	74 (19%)	46 (17%)	3 (1%)	212
	Haha	42 (18%)	39 (11%)		31 (8%)	24 (9%)	28 (14%)	164
	Wow	62 (27%)	53 (15%)	42 (11%)		67 (25%)	58 (29%)	282
	Sad	71 (31%)	11 (3%)	7 (2%)	36 (9%)		**77 (38%)**	202
	Angry	14 (6%)	7 (2%)	12 (3%)	16 (4%)	**39 (15%)**		88
Total Confusions		229 (100%)	353 (100%)	369 (100%)	398 (100%)	265 (100%)	201 (100%)	1815

We computed confusion matrices (see Tables 3 and 4) to further contextualize these confusions. Data along the vertical of each matrix refers to confusions that occurred when the sonification in the column header was observed. Data along the horizontal of each matrix refers to confusions of the Reaction in the row header when the sonification in the column header was observed. In Table 3, for example, data in the Like column refers to BVI confusions when a *Like sonification* was observed, while data in the Like row refers to confusions of the Like Reaction when *Love, Haha, Wow, Sad,* and *Angry sonifications* were observed.

7.3.1 Like. *Like sonifications* were confused with the incorrect Reaction 281 times. Of the 52 *Like* confusions made by the BVI group, the Sad Reaction accounted for the largest proportion, followed by Love, Haha, and Wow; *Like sonifications* were never confused with the Angry Reaction. Of the 229 made by the Sighted group, the Sad Reaction accounted for the largest proportion, followed by Wow, Haha, Love, and Angry.

7.3.2 Love. *Love sonifications* were confused with the incorrect Reaction 408 times. Of the 55 *Love* confusions made by the BVI group, the Like Reaction accounted for the largest proportion, followed by Wow, Sad, Angry, and Haha. Of the 353 made by the Sighted group, the Like Reaction accounted for the largest proportion, followed by Wow, Haha, Sad, and Angry.

7.3.3 Haha. *Haha sonifications* were confused with the incorrect Reaction 438 times. Of the 69 *Haha* confusions made by the BVI group, the Like Reaction accounted for the largest proportion, followed by Wow, Love, Sad, and Angry. Of the 369 made by the Sighted group, the Like Reaction accounted for the largest proportion, followed by Love, Wow, Angry, and Sad.

7.3.4 Wow. Wow sonifications were confused with the incorrect Reaction 464 times. Of the 66 *Wow* confusions made by the BVI group, the Like Reaction accounted for the largest proportion, followed by Love, Sad, Haha, and Angry. Of the 398 made by the Sighted group, the Like Reaction accounted for the largest proportion, followed by Love, Sad, Haha, and Angry.

7.3.5 Sad. Sad sonifications were confused with the incorrect Reaction 318 times. Of the 53 *Sad* confusions made by the BVI group, the Like Reaction accounted for the largest proportion, followed by Angry, Wow, Love, and Haha. Of the 265 made by the Sighted group, the Like Reaction accounted for the largest proportion, followed by Wow, Love, Angry, and Haha.

7.3.6 Angry. Angry sonifications were confused with the incorrect Reaction 242 times. Of the 41 *Angry* confusions made by the BVI group, the Wow Reaction accounted for the largest proportion, followed by Sad, Like, Haha, and Love. Of the 201 made by the Sighted group, the Sad Reaction accounted for the largest proportion, followed by Wow, Like, Haha, and Love.

7.4 Performance

We examined the performance of each sonification that ranked in the top 50% of performance, based on our minimum criteria to be considered effective. Tables 5 and 6 provide a summary of sonifications that ranked in the top 50% in performance for the BVI and Sighted groups, respectively. In total, 21 different sonifications achieved accuracy rates greater than 50%; 9 sonifications were common to both groups (listed in **bold** in Tables 5 and 6).

7.4.1 BVI Performance. Sonifications for the Angry, Sad, Like, and Wow Reactions ranked in the top 50% of performance. Angry was represented most often with 5 sonifications, followed by Sad with 4 sonifications. Like and Wow were both represented once. Haha and Love sonifications did not rank in the top 50% of performance: Haha (A8) – 46% and Love (A16, A22, A28) – 46% were the closest, respectively.

Sonifications from Design 2 outperformed sonifications from all other paradigms with an overall accuracy rate of 56%, followed by Designs D3.4 (45%), D3.3 (44%), D3.1 (33%), D3.2 (33%), D3.5 (33%), D1 (23%), and D3.6 (23%). As shown in Table 7, D2 produced 3 sonifications that ranked in the top 50%, the most of any paradigm.

7.4.2 Sighted Performance. Sonifications for the Angry, Haha, Sad, Like, and Wow Reactions ranked in the top 50% of performance. Like and Angry were represented most often with 6 sonifications, followed by Sad with 5. Haha and Wow both ranked once. Love was the only Reaction without a sonification with an accuracy rate of at least 50%: A34 (Love) – 45% was the closest.

Sonifications from Design 2 outperformed sonifications from all other design paradigms with an overall accuracy rate of 59%, followed by Designs D3.1 (45%), D3.5 (43%), D3.4 (43%), D3.2 (42%), D3.3 (40%), D3.6 (36%), and D1 (20%). As shown in Table 8, D2 produced the 3 best performing sonifications.

Table 5. Top 50% of sonifications for the BVI group. Sonifications that were common to both groups are listed in **bold**.

Sonification ID	Reaction	Accuracy Rate	Effectiveness Tier	Design Paradigm
A7	**Angry**	**82%**	**3**	**D2**
A25	**Angry**	**82%**	**3**	**D3.3**
A33	**Like**	**73%**	**4**	**D3.4**
A11	Sad	64%	5	D2
A12	**Wow**	**64%**	**5**	**D2**
A31	**Angry**	**64%**	**5**	**D3.4**
A35	**Sad**	**64%**	**5**	**D3.4**
A37	**Angry**	**64%**	**5**	**D3.5**
A17	**Sad**	**55%**	**6**	**D3.1**
A19	**Angry**	**55%**	**6**	**D3.1**
A29	Sad	55%	6	D3.3

Table 6. Top 50% of sonifications for the Sighted group. Sonifications that were common to both groups are listed in **bold**.

Sonification ID	Reaction	Accuracy Rate	Effectiveness Tier	Design Paradigm
A12	**Wow**	**88%**	**2**	**D2**
A7	**Angry**	**84%**	**2**	**D2**
A8	Haha	83%	3	D2
A37	**Angry**	**77%**	**3**	**D3.5**
A19	**Angry**	**75%**	**4**	**D3.2**
A13	Angry	73%	4	D3.1
A25	**Angry**	**67%**	**5**	**D3.3**
A31	**Angry**	**66%**	**5**	**D3.4**
A33	**Like**	**63%**	**5**	**D3.4**
A39	Like	63%	5	D3.5
A23	Sad	61%	5	D3.2
A15	Like	59%	5	D3.1
A45	Like	59%	5	D3.6
A27	Like	58%	6	D3.3
A17	**Sad**	**56%**	**6**	**D3.1**
A21	Like	56%	6	D3.2
A35	**Sad**	**56%**	**6**	**D3.4**
A47	Sad	56%	6	D3.6
A41	Sad	52%	6	D3.5

Table 7. BVI Performance by Design Paradigm. Best performing scenarios appear in **bold** and parenthesis.

Design Paradigm	*Like*	*Love*	*Haha*	*Wow*	*Sad*	*Angry*	Total	Accuracy Rate
D1	4	4	3	1	1	2	15	23%
(D2)	5	4	**(5)**	**(7)**	**(7)**	**(9)**	**(37)**	**(56%)**
D3.1	3	**(5)**	1	2	6	5	22	33%
D3.2	5	**(5)**	1	3	2	6	22	33%
D3.3	4	**(5)**	1	4	6	**(9)**	29	44%
D3.4	**(8)**	4	2	2	**(7)**	7	30	45%
D3.5	4	4	4	1	2	7	22	33%
D3.6	3	2	2	2	4	2	15	23%

Table 8. Sighted Performance by Design Paradigm. Best performing scenarios appear in **bold** and parenthesis.

Design Paradigm	*Like*	*Love*	*Haha*	*Wow*	*Sad*	*Angry*	Total	Accuracy Rate
D1	26	7	9	15	13	6	76	20%
(D2)	28	10	**(53)**	**(56)**	26	**(54)**	**(227)**	**(59%)**
D3.1	38	28	13	9	36	47	171	45%
D3.2	36	18	13	7	**(39)**	48	161	42%
D3.3	37	24	13	7	28	43	152	40%
D3.4	**(40)**	**(29)**	11	6	36	42	164	43%
D3.5	**(40)**	27	12	5	33	49	166	43%
D3.6	38	16	19	9	36	22	140	36%

8 DISCUSSION

This study aimed to demonstrate the efficacy and viability of sonification as a universally-accessible modality to convey emotion for both BVI and sighted social media users. Not only do our results suggest that sonification is effective at conveying the emotions that comprise each Facebook Reaction, but given the relevance of this research to contemporary communication platforms and technologies, it is plausible that sonification and auditory displays could enhance the communication of emotion on a variety of CMC platforms. We reflect on our findings with respect to our research questions.

8.1 RQ1: How effective is sonification as a means of conveying the sentiments that comprise each Facebook Reaction?

With no training or prior exposure to our sonifications [45], the BVI and Sighted groups achieved overall accuracy rates of 36% and 41%, respectively, both of which were found to be significantly greater than the probability of a participant making an accurate selection at random (16.7%). The overall mean accuracy rate was 40%. Additionally, 21 different sonifications achieved accuracy rates of at least 50%, meeting our minimum criteria to be considered an effective sonification; 9 sonifications were common to both groups. *Angry* (60%), *Like* (53%), and *Sad* (47%) *sonifications* were accurately matched most often, whereas *Love* (32%), *Haha* (27%), and *Wow* (23%) *sonifications* were accurately matched least often. In this section, we discuss the overall performance of our sonifications.

8.1.1 Like. Like sonifications performed well in this study; 1 sonification was represented in the top 50% of performance for the BVI group and 6 were represented for the Sighted group. However, participants selected the Like Reaction 1290 times during this study, a proportion that was significantly greater than that of the other five Reactions. Only 319 of those selections were accurately associated with a *Like sonification*. Therefore, participants incorrectly associated an observed sonification with the Like Reaction 971 times. The Like Reaction's exceedingly high selection rate impedes our ability to interpret the effectiveness of our *Like sonifications* in aggregate.

While the overall accuracy rate for *Like sonifications* is relatively high at 53%, it required more than one-third of all selections made during the study to achieve. These results indicate that participants overwhelmingly associated any observed sonification with the Like Reaction. They also indicate that there are qualities shared between the Like Reaction and the Love, Haha, Wow, and Sad Reactions. While commonality between Like and Love Reactions was expected, commonality between Like and Sad Reactions was not. Given this high selection rate, we surmise that participants defaulted to the Like Reaction when they were unsure of the correct association (i.e., guessing because they did not know, or guessing for the sake of progressing through the study). It also suggests that many of our sonifications are inadvertently forming associations with *both* the Like Reaction *and* the intended (other) Reaction.

An analysis of confusions supports these assertions as the Like Reaction maintains a high selection rate regardless of the observed sonification. Further, we note that the exceedingly high selection rate of the Like Reaction, no matter the observed sonification, complicates our ability to interpret confusions of other sonifications with the Like Reaction. Further analysis of confusions shows that 813 of the 1290 selections of the Like Reaction were made when participants observed a positively-valenced sonification: *Love, Haha, and Wow*. Interestingly, participants associated a *Sad* or *Angry sonification* with the Like Reaction more often than anticipated.

Overall, these findings suggest that *Like sonifications* require exceedingly rigid design specifications to ensure they are, at a minimum, forming associations with the Like and Love Reactions, and that *Like sonifications* must be validated to ensure that they meet a minimum, acceptable threshold of association with the Haha, Wow, Sad, and Angry Reactions.

While it was challenging to interpret these results for our *Like sonifications* in aggregate, Sonification A33 emerged as the best performing *Like sonification*, ranking in Tier 4 of the Sonification Effectiveness Hierarchy for the BVI group (73%) and Tier 5 for the Sighted group (63%), and will be discussed further in Section 8.2.

8.1.2 Angry. Angry sonifications were among the best performers in the study; 5 sonifications were represented in the top 50% of performance for the BVI group and 6 were represented for the Sighted group. Overall, participants selected the Angry Reaction 472 times, far less often than the expected count of 600. Of those selections, 358 were accurate out of a possible 600, resulting in a relatively high accuracy rate of 60%. The high accuracy rate for *Angry sonifications* and the low selection rate for the Angry Reaction suggest that overall our *Angry sonifications* are effective at forming an association with the Angry Reaction. Of the remaining 114 inaccurate selections of the Angry Reaction, 49 permissible confusions occurred when a *Sad sonification* was observed and 65 confusions occurred when sonifications for the 4 remaining Reactions were observed. Given that the Angry Reaction is overwhelmingly the most negatively-valenced Reaction and the other Reactions are considerably more positively-valenced (excluding Sad), the low selection rate also indicates that sonifications for the other 5 Reactions are not forming an association with the Angry Reaction.

Participants confused *Angry sonifications* with the incorrect Reaction 242 times, with the Sad Reaction – the only other negatively-valenced Reaction – accounting for 87 such confusions. While these are permissible confusions as outlined in Section 7.3, it is evident that the Angry and Sad Reaction constructs ought to be explored further to identify latent qualities that are unique to each, such that they can be incorporated into their sonifications to strengthen their associations, respectively. The remaining 155 confusions of *Angry sonifications* were distributed between the 4 remaining Reactions. Surprisingly, Wow and Like Reactions combined to account for 115 confusions, which suggests that some *Angry sonifications* possess qualities that are shared between the Wow and Like Reactions. Furthermore, these results suggest that when an *Angry sonification* was observed, participants were able to consistently classify it as either negatively-valenced or nonpositively-valenced, resulting in high accuracy rates for *Angry sonifications* and low confusion rates with other positively-valenced Reactions – except Like, as we've already discussed its effects on interpretability.

Overall, these results suggest that *Angry sonifications* are effective at forming an association with the Angry Reaction. However, we surmise that this is due, in part, to the Angry Reaction's standing as the most negatively-valenced of the 6 Reactions. Though participants were able to consistently associate *Angry sonifications* with the Angry Reaction, we are unable to conclude if this was due to their negative-valence, the overall quality of the sonifications, the stark contrast in the sonification design principles of the other 5 Reactions, or some combination of the three. We must reiterate that our goal was not to merely demonstrate that a sonification (in this case, *Angry*) could be identified through process of elimination, but that sonifications informed by evidence-based design can form associations with their *intended* Reaction based primarily on the merits of the sonification.

Sonification A7 emerged as the best performing *Angry sonification*, ranking in Tier 2 among both groups (BVI = 82%, Sighted = 84%), and will be discussed further in Section 8.2.

8.1.3 Sad. *Sad sonifications* performed well in this study; 4 sonifications were represented in the top 50% of performance for the BVI group and 5 were represented for the Sighted group. Overall, participants selected the Sad Reaction 544 times, slightly less than the expected count of 600. Of those selections, 282 were accurate out of a possible 600, resulting in an accuracy rate of 47%. Of the remaining 262 inaccurate selections of the Sad Reaction, 87 permissible confusions occurred when an *Angry sonification* was observed and 175 confusions occurred when a positively-valenced sonification was observed. This indicates that *Love, Haha, and Wow sonifications* are not forming an association with the Sad Reaction.

Participants confused *Sad sonifications* with the incorrect Reaction 318 times, with 49 permissible confusions occurring with the Angry Reaction and 269 confusions distributed between the 4 remaining positively-valenced Reactions. These results indicate that overall, participants were able to consistently associate a *Sad sonification* with the Sad Reaction. However, the confusions with other positively-valenced Reactions (except Like) suggest that overall *Sad sonifications* possess some shared qualities with Love and Wow Reactions.

Sonification A35 emerged as the best performing *Sad sonification*, ranking in Tier 5 for the BVI group (64%) and Tier 6 for the Sighted group (56%), and will be discussed further in Section 8.2.

8.1.4 Love. *Love sonifications* did not perform as well as anticipated. However, due to the similarity between the Like and Love Reaction constructs, we anticipated a degree of confusion that would impair their interpretability. There were no *Love sonifications* represented in the top 50% of performance – the closest candidates emerging from the BVI group are A16, A22, and A28, each of which had an accuracy rate of 46%; the closest candidate emerging from the Sighted group was A34 with an accuracy rate of 45%. Overall, participants selected the Love Reaction 455 times, far less often than the expected count of 600. Of those selections, 192 were accurate out of a possible 600, resulting in a low accuracy rate of 32%. Of the remaining 263 inaccurate selections of the Love Reaction, 206 confusions occurred when a positively-valenced sonification was observed, and 57 confusions occurred when a negatively-valenced sonification was observed. *Love sonifications* were strongly associated with the Like Reaction, which are permissible confusions. These results indicate that participants are able to discern that *Love sonifications* are positively-valenced, but they consistently confused them with the Like Reaction.

Interestingly, confusions of *Wow sonifications* with the Love Reaction accounted for the greatest proportion. This result indicates that there are qualities shared between Love and Wow Reactions, and by extension, the Like Reaction. Given the similarities between the Like and Love Reactions, and these findings indicating some similarity between Love and Wow, we believe that it follows logically there may also be some shared quality between Like and Wow Reactions.

Although none of the *Love sonifications* ranked in the top 50% of performance, we could leverage the existing 'Like' metaphor to produce a more effective *Love sonification*. Anecdotal data gathered during the preliminary phase of this research revealed that Facebook users often view the Love Reaction as an extension of the Like Reaction (i.e., "Like++" or "super Like"). As such, we could adjust the sound parameters of an existing *Like sonification* (A33, for example) to deliver a *Love sonification* that is a much more elaborate variant. Based on our results, we'd expect that both BVI and sighted participants would be able to identify this new *Love sonification* since A33 was a leading performer among both groups.

While there was no clear *Love sonification* that emerged as most effective, we propose sonification A34 based on it's accuracy rate of 45% among the Sighted group, the larger of the two groups. A34 will be discussed further in Section 8.2.

8.1.5 Haha. Haha sonifications did not perform as well as anticipated; 1 sonification was represented in the top 50% of performance for the Sighted group and none was represented for the BVI group. Overall, participants selected the Haha Reaction 362 times, the fewest of all 6 Reactions. Of those selections, 162 were accurate out of a possible 600, resulting in a low accuracy rate of 27%. The low accuracy rate of *Haha sonifications* and the low selection rate of the Haha Reaction indicate that overall *Haha sonifications* did not effectively form an association with the Haha Reaction. Of the 438 incorrect selections of the Haha Reaction, the confusions were fairly evenly distributed between the remaining 5 Reactions, indicating that *Haha sonifications* overall did not form an association with the Haha Reaction, but that they may also share qualities with the other remaining Reactions, but not enough such that they are consistently confused with other Reactions.

Overall, these results indicate that *Haha sonifications* did not effectively elucidate the latent qualities of the Haha Reaction to the degree that they are easily differentiable and identifiable. It is evident that *Haha sonifications* require rigid design specifications to ensure that they are forming an association with the Haha Reaction.

Sonification A8 emerged as the most effective *Haha sonification*, achieving an 83% accuracy among the Sighted group. While it did not rank in the top 50% of performance for the BVI group, we propose it as a candidate given its high performance among the larger group. A8 will be discussed further in Section 8.2.

8.1.6 Wow. Wow sonifications did not perform as well as anticipated; only 1 sonification was represented in the top 50% of performance for the Sighted and BVI groups. Overall, participants selected the Wow Reaction 477, far less often than the expected count of 600. Of those selections, 136 were accurate out of a possible 600, the fewest of all the Reactions, resulting in a low accuracy rate of 23%. The low accuracy rate of *Wow sonifications* and the low selection rate of the Wow Reaction indicate that overall *Wow sonifications* did not effectively form an association with the Wow Reaction. Of the 464 incorrect selections of the Wow Reaction, 263 confusions occurred when a *Like sonification* was observed, and the remaining confusions were fairly evenly distributed between the remaining 4 Reactions, indicating that *Wow sonifications* overall did not form an association with the Wow Reaction, but that they may also share qualities with the other remaining Reactions, but not enough such that they are consistently confused with other Reactions.

Overall, these results indicate that *Wow sonifications*, much like *Haha sonifications*, did not effectively elucidate the latent qualities of the Wow Reaction and also require rigid design specifications to ensure that they are forming an association with the Wow Reaction.

Sonification A12 emerged as the most effective *Wow sonification*, achieving an accuracy of 88% and 64% between the Sighted and BVI groups, respectively. It was also the only *Wow sonification* represented in the top 50% of performance. A12 will be discussed further in Section 8.2.

8.1.7 Summary. In this study, we have demonstrated that sonifications are effective at conveying the sentiments that comprise each Facebook Reaction. However, there were varying degrees of effectiveness that our sonifications achieved overall. We attribute the differences in performance to the shared commonality of certain constructs (i.e., Like and Love) and the overall discriminability of our sonifications. These results permit the interpretation of sonification performance in aggregate. In Section 8.2, we discuss the design paradigms, strategies, and approaches that contributed to the success of the leading sonification candidates: Angry, A7 from Design 2; Haha, A8 from Design 2; Wow, A12 from Design 2; Like, A33 from Design 3.4; Love, A34 from Design 3.4; and Sad, A35 from Design 3.4.

8.2 RQ2: How ought sonifications of emotion be designed such that they are distinct and easily identifiable, yet differentiable from each other?

8.2.1 Design 1: Mimicry. Design 1 did not produce any sonifications to rank in the top 50% of performance. This performance could be attributed, in part, to the online evaluation tool's inability to display animated images (i.e., GIFs.), considering that Design 1 leverages the visual mimicry metaphor. Had this functionality been available, these sonifications may have better elucidated the mimicry concept amongst the Sighted group. Further, these results, particularly among the BVI group, indicate that the musical notes we selected did not create a strong association with the underlying Reactions. The *Like sonification*, A3, was the best performer from Design 1. Sonification A3 utilized musical notes that were mapped to the moments in time that the Like Reaction's 'Thumps-Up' animation transitioned between its ascended, descended, and normal states. Additionally, we used brighter notes to further form an association with the Like Reaction. Though A3 was the leading performer from Design 1, the high selection rate of the Like Reaction complicates our ability to make inferences about A3's overall level of effectiveness. While the mimicry metaphor could prove effective, these results warrant further examination in a more representative context where participants can visually experience the Facebook Reaction animations and then create an association between the Reaction and the sonification.

8.2.2 Design 2: Paralanguage. Overall, Design 2 produced 3 of the most effective sonifications among the Sighted group. The results indicate that the paralanguage concept was particularly effective for the anthropomorphic Reactions, specifically Haha (A8), Wow (A12), and Angry (A7). The *Haha sonification* utilized a young child's playful laughter as a representation of the Haha Reaction, the *Angry sonification* utilized the sound of an adult male angrily grunting to form an association with the Angry Reaction, and the *Wow sonification* utilized the sound of an adult female gasping in awe to form an association with the Wow Reaction. The high accuracy rates for these sonifications indicate that the embodiment metaphors were effectively mapped to their respective Reactions. Surprisingly, the *Haha sonification* did not rank in the top 50% of performance for the BVI group, but was the third-best performer in the Sighted group. Tuning the intensity of the laughter and exploring different manifestations of human laughter may lead to improved performance for the BVI group.

In sum, the results for these sonifications indicate that human vocalization sounds and other forms of paralanguage are effective at forming associations with the anthropomorphic Reactions. However, the *Sad sonification*, which utilized the sound of a human pouting in disappointment, was not as effective. Future investigations ought to apply insights from Cowen [13] to examine the variety of ways that humans embody sadness. The *Like sonification* was mapped to the sound of a cash register and the *Love sonification* was mapped to the sound of birds twittering. We note that these Reactions, while having human elements, do not have obvious sounds or utterances that can be mapped to their respective constructs.

8.2.3 Design 3: Simple Music. Overall, Design 3 utilizes multiple variations in tempo and timbre of musical notes to create associations with each Reaction. In particular, Design 3.4 (Simple Music: 2x Tempo) produced the 3 leading candidates for Like (A33), Love (A34), and Sad (A35). The *Angry sonifications* were overwhelmingly the best performers from this design. As discussed in Section 8.1.2, this is likely attributed, in part, to the negative-valence of the Angry Reaction and the composition of musical notes that helped form that mapping. *Like sonifications* utilized compositions of very simple notes (comparable to dinging bells) to form an association with the way the Like Reaction is actually used by Facebook users. These designs produced several *Like sonifications* that ranked in the top 50% of performance, however, the Like Reaction's high selection rate impedes our ability to attribute these high accuracy rates to their overall effectiveness. *Love sonifications* were designed to be extensions of the *Like sonifications*, commensurate with how the Like and Love Reactions are used in practice. The composition of *Love sonifications* was more elaborate in pitch range and rhythm to differentiate itself from the *Like sonifications*, but similar enough in composition to indicate a degree of similarity with it. *Sad sonifications* utilized less notes and descending pitch to create an association with the Sad Reaction. The *Haha sonification* utilized a high-pitch composition of notes that were instantiated early in the sound. The results indicate that this was not effectively elucidated. The *Wow sonification* used a very bright composition of notes to create an association with the Wow Reaction, but this was also not effectively elucidated.

9 DESIGN RECOMMENDATIONS

Based on the results of this study, we offer guidelines for the design of universally-accessible sonifications that convey emotion. This set of guidelines are to be considered collectively.

Paralanguage and human vocalization sounds are very effective. Paralanguage, such as laughter or crying, are innate conditions that are easily recognizable by humans [35]. These paralinguistic cues are inherently mapped to an array of specific emotions and feelings that humans experience [53]. The recent work of Cowen et al. supports the relationship shared between emotions and certain human vocalization sounds [13]. Through the sonification design process, a designer can engineer these cues to convey a specific variant of an utterance. For example, one could imagine the difference between mild laughter and hysterical laughter. Each form of laughter could elucidate a specific emotion.

Cultural determinants must be considered. As with any user-centered design endeavor, you must know your users. The nature of emotional expression may differ between and within cultures [36]. Therefore, it is paramount that designers ingratiate themselves with their users when identifying emotions that they wish to design for. This process may require the use of ethnographic methods but helps ensure that the sonifications produced are representative of their users. We consider this to be the most important guideline, as the following guidelines are contingent upon the designer's level of cultural awareness.

Leverage the use of analogy and metaphor. The use of analogy and metaphor is a commonly-used design technique in auditory displays [50]. By identifying and leveraging the shared relationships between a specific experience and emotion, designers can generate unique sonifications that can recreate that moment in time.

Constrain, chunk, and properly valence your collection of sonifications. Designers ought to constrain the collection of sonification emotions that they present to minimize the cognitive load on the user [5, 27]. Requiring users to memorize or parse through multiple sonifications can be an onerous task and may lead to abandonment of the sonifications altogether. For larger sets of emotions, we suggest chunking [10] the collections of sonifications into several smaller collections. These smaller collections should possess emotions that are distinct from each other to improve discriminability. Lastly, designers should properly valence their collection of emotions. This enables users to discern increases in emotional magnitude (e.g., like versus love; or sad versus devastated) as they navigate the sonifications.

10 FUTURE WORK

This research demonstrates the efficacy of sonification as a means of conveying emotions to BVI and sighted users. While we identified successful sonification design paradigms, we assert that they still warrant further investigation before they're recommended for use on social media platforms. Future studies would benefit from a qualitative examination regarding users' perceptions and opinions of these sonifications. Engaging with additional sighted and BVI users in a co-design context would also provide valuable insights into the ways that users perceive and express emotions. Additionally, we have included a demo video[12] that highlights how these sonifications would be used on Facebook from the perspective of an Apple VoiceOver user. All assets developed throughout this study have also been made available[13] for academic use within and outside the HCI and CSCW communities.

Most importantly, this research highlights the need for a deliberate investigation into the nature of emotion in CMC systems. Derks' [16] survey of the CMC literature concluded that the conveyance of emotion is not an issue. While we agree with these findings, we believe the omnipresence of social media, in conjunction with recent developments regarding the relationship between social media and mental health [21], warrants further inquiry into the role and quality of emotional expression in CMC systems. Given the technological advances of the last decade, we may identify discernible differences in the role of emotion in CMC systems across generations and cultures.

Lastly, we seek to explore the accessibility of paralinguistic and nonverbal communication cues on CMC systems. The COVID-19 pandemic has expedited the global adoption of computers. We believe this warrants an exploration of the overall accessibility of communication. Thus, we encourage our peers to critically examine the quality, nature, and accessibility of communication in online CMC systems.

11 CONCLUSIONS

In this paper, we present one of the first explorations into the use of sonification to convey emotion in CMC systems. First, we explored the design and evaluation of a suite of accessible sonifications to convey emotion in text-based communication platforms, using the Facebook Reactions feature as a conceptual framework. We describe an intensive user-centered design process, in which we collaborated with domain experts to inform the design of these sonifications. We evaluated our sonifications through an online sound-matching activity, inspired by Bonebright et al. [5, 27]. We examined the results and evaluated them against our metrics, concluding that sonifications can

[12]https://drive.google.com/file/d/1Q9PiJpTIxAXmKKW9yvuC3ih8H6dZN7kF/view?usp=sharing
[13]https://drive.google.com/drive/folders/1y7Pk_aMHDa_HasI8PiiaWiwFIZJp9W79?usp=sharing

effectively convey the sentiments inherent to emotions. We provide design guidelines to aid in the generation of accessible sonifications of emotion. Finally, we call for a much-needed inquiry within the HCI and CSCW communities into the faculties surrounding CMC systems. We believe that this work will further the discourse on the accessibility of CMC systems.

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