Music as an Auditory Display: Interaction Effects of Mode and Tempo on Perceived Urgency

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Currently, there are very few guidelines on parameters needed to create an effective auditory display. Auditory displays can be intrusive and may not be used effectively if they are poorly designed. However, music is often in our environments as ambient noise and, instead of being intrusive, can be perceived as making the environment calmer and more productive. We present the initial steps of exploring the option of using music as a medium to develop an auditory display capable of conveying normal state information and warning information. An important feature that may impact the effectiveness of auditory warnings is perceived urgency: the impression of urgency that a sound evokes on a listener. To explore whether music could convey urgency as needed for auditory warnings, we evaluated four different musical phrases that varied in time and key signature as a method of measuring the effects of mode and tempo on perceived urgency. The effectiveness of the study was tested with twenty subjects split into a two by two factorial design: gender (male vs. female) and musical experience (experienced vs. non-experienced). The applications of this research can help develop concrete guidelines when designing effective auditory displays in order to improve users' performance when dealing with complex interfaces.

INTRODUCTION

Auditory displays have the potential of using sound to assist human activity, reduce work load, and explore complex data (Barrass & Kramer, 1999). Auditory displays have an advantage over visual displays as they capture a user's peripheral awareness and transmit information regardless of the direction a user is looking (Watson, 2004). True auditory sonifications map quantifiable system data to acoustic dimensions such as tempo and tone (Barrass & Kramer, 1999). Auditory displays, like visual displays, must convey both normal data, but also properly convey warning information. One of the particular challenges with auditory warnings, however, is that, due to the pervasiveness of auditory information, in many cases auditory displays have been turned off or ignored as they are loud and intrusive (Seagull & Sanderson, 2001; Momtahan & Tansley, 1989).

Music is often in our environments as ambient noise, and instead of being intrusive, can make the environment calmer. In other cases though, studies have shown that background music can be as distracting as noise (Furnhma & Strbac, 2002). However, if music is used in the correct situation, it can be advantageous. For example, as seen by Ullmann (2008), majority of doctors and nurses working in an operating room listen to music as it increases efficiency as well as provides a calming effect. Other emotions such as sadness and happiness can be evoked through music which cannot be achieved using pure tones.

Effective sonifications are used to communicate information in which users must be able to discriminate between. Auditory discriminability is tied to familiarity as shown by Paquette and Peretz(1997): familiar tones such as music can increase the rate of detecting pitches with fewer errors than non-familiar tones. Lutkenhoner (2006) observed a stronger neurological response to piano tones as compared to pure tones explaining Paquette and Peretz claim. Music might be able to provide increase response time and better discriminability, both important factors when designing auditory displays.

The use of music as a medium in developing sonifications, compared to many conventional pure-tones signals, opens up many opportunities with a large design space. Utilizing the complexity of music, we are able to take advantage of its many characteristics and design less intrusive auditory displays.

Perceived Urgency in Sound

Sonifications are only able to enhance a user's experience, if one is able to interpret and understand the meaning of the information presented. Walker and Kramer (2005) discovered that certain auditory characteristics were intuitively associated to certain types of data. These preferences existed even when participants were trained to recognize different types of mapping.

One of the most critical mappings of auditory displays is perceived urgency: the impression of urgency that a sound evokes on a listener. Mismatch in perceived urgency of a warning to an event has been observed experimentally in operating and recovery rooms (Momtahan and Tansley, 1989). Incorrect mappings can result in confusion, congestion and desensitization (Momtahan and Tansley, 1989). Perceived urgency is critical as it can help users with prioritization of tasks and reduce response time. Researchers must extensively examine factors that may influence how users may perceive sonifications to prevent confusion.

Preliminary research in auditory warning design by Edworthy (1991) illustrated the relationship between pulse parameters and perceived urgency. Edworthy (1991) discovered that shorter pulse durations resulted in increasing perceived urgency of an alarm. However, perceived urgency of sonifications in particular music is relatively unexplored. In this work, we have explored whether music or more precisely parameters of music provide a useful mapping to the perception of urgency. If possible, this would mean that music

based displays, incorporating warning information might be possible. This will allow designers to build displays that provide information while simultaneously take advantage of the known benefits of music.

Effects of music

Research has explored the effects of manipulating single musical elements or specific musical compositions on human emotion response, but little is known about the effects of different musical elements on the perception of urgency. Wedin (1972) has demonstrated that variations in musical intensity, mode, pitch, rhythm, tempo, and texture have some influence on emotional response.

Previous researchers have concluded: music in major modes has been associated with happy emotional responses whereas music in minor modes has been associated with sad emotional responses (Crowder, 1984). Variations in tempo have consistently been associated with different emotional responses: increased tempo is associated with happy emotions while slow tempo is associated with sad emotions (Dalla Bella et al., 2001). However, measuring the influence of a specific musical element is difficult as most musical compositions consist of an intricate combination of many different musical elements. Studying the interaction effects of musical elements is important as experiments that only test a single musical element (e.g. major vs. minor modes) have little ecological validity since users rarely perceive music solely as a function of a single element (Sopchak, 1955).

Gender is an important factor when considering at the relationship between music and emotion (Webster & Weir, 2005). Women are noted to have larger emotional responses when listening to music in both major and minor modes. Musical experience is also noted to play a subtle role, interacting with both texture and mode (Webster & Weir, 2005). For this reason, gender should be considered in emotional evaluations of music.

Goals and Hypothesis

In the present experiment, we utilized four different musical phrases that varied in time and key signature as a means of exploring perceived psychoacoustic urgency. We hypothesized that a faster tempo and major modes would result in higher urgency ratings. Among the participants, we hypothesized that gender would be a factor in perceived urgency while musical experience would not.

METHOD

Participants

Twenty undergraduate and graduate students from the University of Waterloo participated in the study. Their ages ranged from 19 to 28 (M=21.1, SD = 2.41) with ten males and ten females. Nine participants had no musical experience while eleven participants had a reported mean of 6.25 years of musical experience (SD = 4.22). All participants reported having normal or corrected to normal hearing. Participants were compensated with fifteen dollars for an hour and a half session. All procedures obtained clearance from the University of Waterloo, Office of Research Ethics (ORE).

Design

In this study, we focused on the interactive effects of different music elements on perceived urgency. The study employed a mixed factorial design: 2(mode: major vs. minor) x 6 (tempo: 60, 80, 100, 120, 140, 160bpm) within- participant factorial design and a 2(gender: male vs. female) x 2(experience: non-experience vs. experienced) between-participant design.

Stimuli

Twelve variations of each of the four different musical phrases from Webster and Weir (2005) were used for the study. All four phrases were five-measure sequences that varied in time and key signature to increase the variations within the stimuli. All four phrases can be seen in Figure 1. The order of presentation of the phrases was randomized.

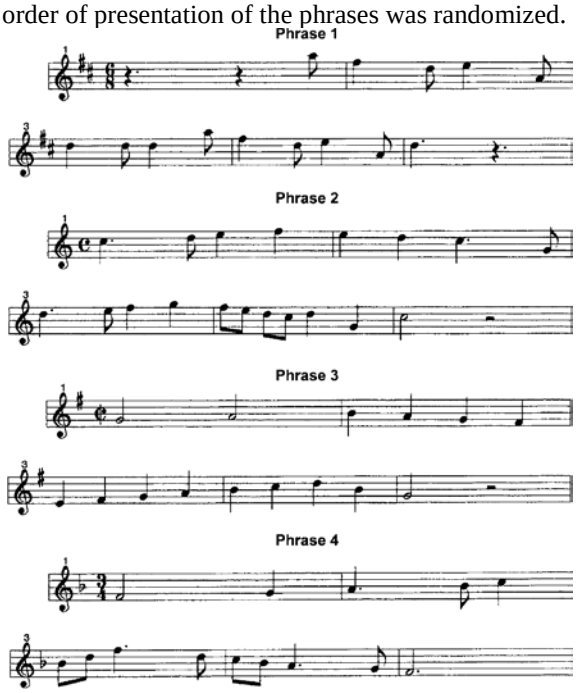

Figure 1: The four major melodic phrases used in the experiment Webster and Wier (2005)

Following the procedures outlined by Kastner and Crowder (1990) and Rigg (1940), each phrase was transcribed in Finale 2012. Each phrase was then transcribed into its respective parallel minor modes (three semi-tones down). The two variations of each phase: major and minor were then produced at six different tempos: 60 beats per minute (bpm), 80 bpm, 100 bpm, 120 bpm, 140 bpm, and 160 bpm. Each tempo was selected based off Rigg(1940). Across all four musical phrases a total of 48, unique musical phrases were created.

A MIDI module provided by Image-Line's Fruity Loops Studio was used to convert the tonal signals produced in

Finale 2012 into the timbre of a grand piano. The selection of the timbre is similar to the one in Webster and Weir (2005) as this timbre is likely to be more realistic and familiar to participants than sine waves or other instruments.

All auditory stimuli for the experimental task were recorded to WAV files. The stimuli duration ranged between 6 seconds and 20 seconds. The musical pieces contain musical notes ranging from E3 to A2 which corresponds to a frequency range of 110.00 Hz to 168.81 Hz. The frequency was within the normal hearing frequency range of humans.

Apparatus

The experiment took place in an attenuated room with an averaging gain of 38.90 dBA measured using Fruity Loops Studio. The room had no windows with florescent tubes as lighting. In this study, a Lenovo Intel Core 2 CPU was served as the host computer to record responses with a mouse and keyboard. The auditory stimuli from the host computer were presented to the participant binaurally over an AKG 501 open-air circumaural headset, with a frequency response range of 16Hz – 30 kHz (Vienna, Austria). The experimental software was created using Visual Studio.

Procedure

Upon arrival at the research laboratory, participants completed a formal consent form and a background questionnaire about their age, sex, and hearing capabilities.

For the preliminary task, participants were provided with a detailed pre-study information package. After the explanation of the experiment, participants completed a brief practice session to familiarize with the six different tempos.

After the practice, participants began the 90-minute session. During the session, participants were asked to assess the urgency of the presented signals and discriminate among the different tempos. The rating would be recorded on an urgency mapping scale based on Edworthy's urgency mapping principles described in Arrabito (2004). The scale was a simple scale between 1 and 100, with 1 representing the least urgent and 100 representing the most urgent. The participants were instructed to respond quickly, but not to comprise speed with precision. After each rating, the participants were presented with the next auditory stimulus. The dependent variable in this task would be the rating of perceived urgency. Each participant's performance was monitored and recorded.

All participants were exposed to a total of 48 unique musical phrases that varied in tempo and mode. All 48 sounds were repeated five times for a total of 240 auditory stimuli. The order of presentation was randomized for each participant. After the completion of the task, participants were compensated and released.

RESULTS

Mode and Tempo Effects

All perceived urgency ratings had been normalized before averaged urgency scores were calculated across the four phrases. Figure 2 illustrates the perceived urgency for each condition.

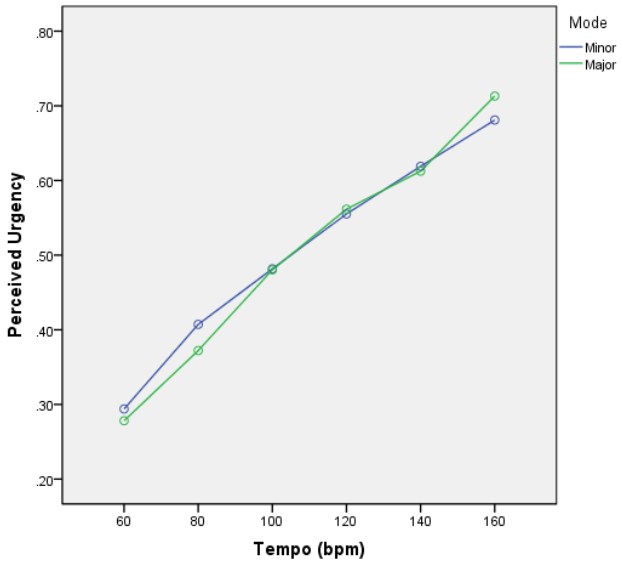

Figure 2: Perceived urgency ratings for all tempos separated by mode.

The perceived urgency scores were subjected to two-repeated measures 2 x 6 (Mode: major, minor; Tempo: 60 bpm, 80 bpm, 100 bpm, 120 bpm, 140 bpm, 160 bpm) within subject. Analysis of variance (ANOVA) was used to examine the effects of tempo and mode on perceived urgency. All model assumptions were met through a test of normality. Preliminary analysis using Mauchly's test revealed that sphericity was violated for tempo (chi-square = 123.172, p <.001). Hence, the degrees of freedom were corrected using Greenhouse-Geisser estimates of sphericity (epsilon = .235 and .731 respectively).

The results showed that there was no significant main effect or interactions with mode. However, a significant main effect of tempo was found, F(1.177, 18.83) = 73.934, p < *.001,* partial eta squared = .822, with both modes showing an increase of perceived urgency with increasing tempos as seen in Table 1. Post-hoc trend analyses showed a significant linear trend of tempo and perceived urgency. In addition, a significant interaction between mode and tempo was also present F(3.565, 16.141) = 5.628, p=.001.

Six one-way repeated measures ANOVA were completed on mode across each tempo. The main effect of tempo can be found at 80 bpm F(1,19) = 6.657, p = *.018* and 160 bpm F(1,19) = 11.306, p = *.003*.

Moderation by Gender and Musical Experience

The effects of gender difference and musical experience on perceived urgency were also measured. No main effect was observed for both gender F(1,16) = 1.087, p = *.313* and musical experience F(1,16) = .439, p = *.517*.

There was an interaction effect between tempo and gender F(5,16) = 2.443, p = *.041*. Large perceived urgency rating

differences could be seen at slower tempos. Figure 3 illustrates the perceived urgency for tempo based on gender. Females on average had a perceived urgency rating range of 0.46 while males had rating range of 0.29. A one way analysis of variance revealed a significant difference between 60 bpm and gender $F(1,18) = 4.440$, $p = .049$. No main or interaction effects of musical experience were observed.

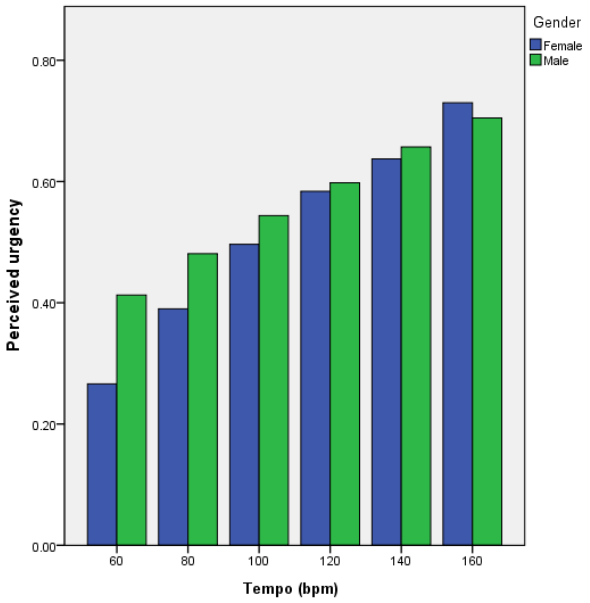

Figure 3: Perceived urgency ratings for all tempos separated by gender.

DISCUSSION

In this study, we evaluated perceived urgency as a function of mode and tempo. We examined six different tempos in increments of twenty beats per minute and two modes: major and minor. The results confirmed our first hypothesis: faster tempos result in a higher perceived urgency. This finding was in agreement with previous results of Hellier and Edworthy (1999), who observed the influence of interpulse interval on perceived urgency. In their research, interpulse interval had a direct positive correlation with perceived urgency. However, in our case, the manipulation of interpulse intervals in a musical domain would be difficult.

It is important to be note that tempo and interpulse interval, while related, are quite different parameters in the case of music. The closest analog to interpulse interval, in the case of music would be inter-note duration. For example, tempo is measured in beats per minute or number of quarter notes in a minute. In music, even at a tempo of 60 beats per minute, inter-note durations are highly variable and reflect the construction of the musical composition. For this reason, while changes in tempo would create a net reduction overall in inter-note duration, because of the variability of inter-note duration, it could not be assumed that the previous urgency relationship with interpulse interval would generalize to music. For this reason, the urgency mapping we found with tempo is interesting and useful. Tempo, regardless of changing inter-note durations, still has a direct positive linear relationship with perceived urgency.

An interesting observation is the relation between emotion and perceived urgency that can be considered by comparing our study to studies of music and emotion. Our results are very similar in pattern to the results of Riggs (1940) and Webster and Weir (2005). This suggests a correlation between urgency and emotion that could be investigated further.

A qualitative interaction can be established in between 100 bpm and 140 bpm. At 80 bpm, minor modes seem to be more urgent whereas at 140 bpm major modes have a larger perceived urgency rating. This suggests that at slower tempos minor modes become more urgent whereas in faster tempos major modes are perceived as more urgent. There seems to be a critical tempo in between 80bpm and 140 bpm at which mode does not play significant role. This observation is reflected in emotional responses as observed by Rigg (1940). A critical tempo at which minor modes become more “sad” may provide an explanation to why minor modes are perceived as more urgent at lower tempos. Other relationships between emotion and perceived urgency can be observed.

In addition, the lack of significance found for the effects of musical experience suggest that musical experience does not affect perceived urgency. This result may imply that interpretation of audio signals may be universal between subject groups. Designers may not need to take an extra factor into consideration when designing auditory displays. However, one factor that must be taken into consideration is gender. As seen in our results, there is a large difference in urgency perception ratings between males and females at slower tempos. Regardless of mode, females showed a larger range of urgency perception rating ranges. Designers of auditory displays must remember to keep this factor in consideration.

The lack of ambiguity of auditory mappings as presented by Walker and Kramer (2005) is a very powerful aspect of sound. In addition, the presence of music is already found in many environments such as the operating room. Music might be a possible choice as a medium for auditory display because of its comforting and non intrusive features.

The most important finding of this study is that music may be able to convey a sense of urgency within users. In the correct situation, adding an extra layer in music can create not only an effective auditory display, but also enhance performance and user experience.

Limitations

One major drawback of the current study was the lack of context for the sonifications. The design of sonifications is often guided by the intended use. Even though the musical phrases were designed for the intent of the use in a long monitoring task, no specific task was provided to leverage the scenario of an operating task. The addition of a primary or secondary task might have affected how a user interpreted and perceived the auditory display.

The music phrases implemented in this study were short and contained simple notes and with only one timbre. In reality, many music pieces contain many layers such as different timbres and dynamics. This complexity presents an

issue as users may be unable to discriminate between a signal and a feature in a musical piece.

Future Work

The interaction effects among mode, intensity, pitch, rhythm, texture, melodic contour and tempo can still be explored. The additional research and observations of interaction effects of the different musical elements will help to design better guidelines for using music as a sonification or as an auditory display. More defined guidelines on designing effective auditory displays will emerge from this research.

Effective auditory display must be able to communicate information successfully and perceive changes in a system. At the same time, users must discriminate not only the source of change within the system but also the magnitude of variation. This parameter is known as discriminability, a factor which is closely related to psychoacoustic discriminability of auditory dimensions. On the path of developing effective displays, discriminability must be another important parameter that must be explored.

CONCLUSION

This study illustrates that music as a subclass of sonifications may have the ability to be mapped onto perceived urgency and to present information to a user effectively. In the auditory domain, regardless of musical experience, tempo and mode may both affect the psychoacoustic perception of urgency. Further investigation would result in the development of a theoretical framework for the design of auditory displays using music, a useful interface that can enhance a user's experience and performance.

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REFERENCES

Arrabito, G. R., Mondor, T., & Kent, K. (2004). Judging the urgency of non-verbal auditory alarms: a case study. *Ergonomics*, *47*(8), 821-840.

Barrass, S., and G. Kramer. (1999). Using Sonification. *Multimedia Systems*, 7: 23-31.

Crowder, R. G. (1984). Perception of the major/minor distinction: I. Historical and theoretical foundations. *Psychomusicology: A Journal of Research in Music Cognition*, *4*(1-2), 3.

Dalla Bella, S., Peretz, I., Rousseau, L., & Gosselin, N. (2001). A developmental study of the affective value of tempo and mode in music.*Cognition*, *80*(3), B1-B10.

Edworthy, J., Loxley, S., & Dennis, I. (1991). Improving auditory warning design: Relationship between warning sound parameters and perceived urgency. *Human Factors*, 33(2), 205-231.

Furnham, A., & Strbac, L. (2002). Music is as distracting as noise: the differential distraction of background music and noise on the cognitive test performance of introverts and extraverts. *Ergonomics*, *45*(3), 203-217.

Hellier, E., & Edworthy, J. (1999). On using psychophysical techniques to achieve urgency mapping in auditory warnings. *Applied Ergonomics*, *30*(2), 167-171.

Kastner, M. P., & Crowder, R. G. (1990). Perception of the major/minor distinction: IV. Emotional connotations in young children. *Music Perception,* 189-201.

Lütkenhöner, B., Seither-Preisler, A., & Seither, S. (2006). Piano tones evoke stronger magnetic fields than pure tones or noise, both in musicians and non-musicians. *Neuroimage*, *30*(3), 927-937.

Momtahan, K., Hetu, R., & Tansley, B. (1993). Audibility and identification of auditory alarms in the operating room and intensive care unit. *Ergonomics*,*36*(10), 1159-1176.

Paquette, C., & Peretz, I. (1997). Role of familiarity in auditory discrimination of musical instrument: a laterality study. *Cortex*, *33*(4), 689-696.

Rigg, M. G. (1940). Speed as a determiner of musical mood. *Journal of Experimental Psychology*, *27,* 566–571.

Seagull, F. J., & Sanderson, P. M. (2001). Anesthesia alarms in context: An observational study. *Human Factors: The Journal of the Human Factors and Ergonomics Society*, *43*(1), 66-78.

Sopchak, A. L. 1955. Individual differences in responses to different types of music in relation to sex, mood, and other variables. *Psychological Monographs*, 69, 1–20**.**

Ullmann, Y., Fodor, L., Schwarzberg, I., Carmi, N., Ullmann, A., & Ramon, Y. 2008. The sound of music in the operating room. *Injury*, 39, 592-597.

Walker, B. N., & Kramer, G. (2005). Mappings and metaphors in auditory displays. *ACM Transactions on Applied Perception*, *2*(4), 407-412.

Watson, M., & Sanderson P. (2004). Sonification supports eyes-free respiratory monitoring and task time-sharing. *Human Factors*, 46(3), 497-517.

Webster, G. D., & Weir, C. G. (2005). Emotional responses to music: Interactive effects of mode, texture, and tempo. *Motivation and Emotion*, *29*(1), 19-39.