NORTHERN ARIZONA UNIVERSITY
The W. A. Franke College of Business

The Perceived Hazard of Earcons in Information Technology Exception Messages: The Effect of Musical Dissonance

Working Paper Series—10-03 | March 2010

T.S. Amer
The W. A. Franke College of Business
Northern Arizona University
P.O. Box 15066
Flagstaff, AZ 86011
928-523-7370
tsamer@nau.edu

Jo-Mae B. Maris
The W. A. Franke College of Business
Northern Arizona University
P.O. Box 15066
Flagstaff, AZ 86011
928-523-7403
Jo-Mae.Maris@nau.edu

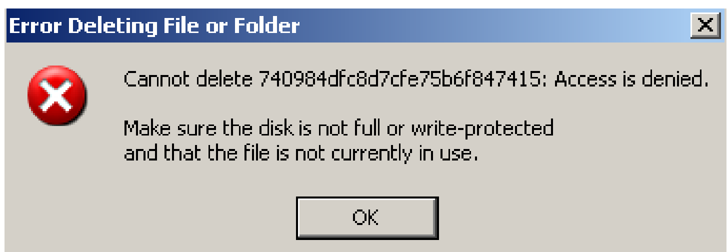
Greg Neal
The W. A. Franke College of Business
Northern Arizona University
P.O. Box 15066
Flagstaff, AZ 86011
928-523-7606
gregory.neal@nau.edu

The Perceived Hazard of Earcons in Information Technology Exception Messages: The Effect of Musical Dissonance

I. INTRODUCTION

Users of information technology (IT) commonly encounter exception messages during their interactions with application programs. Exception messages, sometimes referred to as “dialogs,” appear over the main window of the parent application program and engage the user by offering information and requesting some input (Cooper and Reimann, 2003; Galitz, 2007). Exception messages often are accompanied by earcons. Earcons are non-verbal aural messages of a musical nature used in the human-computer interface to provide information and feedback about some computer object, operation, or interaction (Blattner et al. 1989; Garzonis et al. 2009; Lemmens 2005; Lemmens et al. 2007). Along with other features of exception messages, such as signal words (e.g., “Error”) and signal icons (e.g., a red circle containing an “X”), earcons can be designed to catch the attention of the user to warn of potential technical problems if certain actions are taken or conditions occur (Amer and Maris, 2007). For example, the exception message of Figure 1 is accompanied by a musical earcon with the function of catching the attention of the user as the action of deleting a folder is being executed.

FIGURE 1. Example of an Exception Message Accompanied by an Earcon



There are different levels of hazard that can occur during a user’s interaction with computer applications. For example, accidentally erasing an entire file is more hazardous than attempting to enter incorrect data in a single field during data input. Accordingly, exception messages within IT environments should communicate different levels of hazard in order to achieve so called “hazard matching.” Hazard matching occurs when the severity of the hazard communicated by the exception message matches the level of hazard faced by the user (Amer and Maris 2007; Hellier et al. 2000). Hazard matching is widely recommended as a desirable result in that it improves the informativeness of warnings (Edworthy and Adams 1996; Edworthy 1998; Hellier et al. 2000; Hellier and Edworthy 2006; Momtahan and Tansley 1989; Wogalter and Silver 1990). Amer and Maris (2007) found that different combinations of signal words and icons possess different levels of perceived hazard communicated by an exception message. This paper extends this line of research by examining the perceived level of hazard associated with various earcons that accompany exception messages.

Utilizing the notion of musical dissonance earcons were designed that vary as to their degree of aural disagreeableness along a rank order scale. It is hypothesized that in the context of IT exception messages earcons with a higher degree of musical dissonance (aural disagreeableness) would be perceived as communicating a higher degree of hazard associated with the underlying computing problem. Participants rated the degree of hazard of each earcon presented in a random order in a laboratory experiment. Results of the data analysis indicate partial support of the hypothesis. The implications are that it may be possible to increase the degree of hazard matching in IT environments by designing earcons that accompany exception messages to communicate different levels of perceived hazard of an underlying computer problem.

II. BACKGROUND AND HYPOTHESIS

The structured, musical nature of earcons permits the creation of a wide variety of melodic and harmonic fragments using the dimensions of pitch, timbre, and/or rhythm (Lemmens et al. 2007; Gaver 1989; Pramana and Leung 1999). The earcons that accompany exception messages are usually very short musical patterns of a few notes sounded in sequence or as a chord with duration of 500 ms to one second. For example, the earcons that accompany the Microsoft XP and Vista exception messages such as “New Mail Notification,” “Critical Stop,” and “Error” contain two to three notes sounded for a short duration.[1] The earcons that accompany exception messages share similarities in principle to the auditory alarms and signals that occur in many environments from equipment operations in factories to the auditory alarms associated with burglar alarms, coffee makers and watches (Haas and Edworthy 2006). Though auditory alarms are typically longer in duration than the short sequence of musical notes that comprise earcons both auditory alarms and earcons warn or inform people of a state of the world or system, a potential problem, or actions required to be taken. For example, an auditory alarm in an automobile signals the driver if a passenger’s seatbelt is not fastened. Likewise, and earcon accompanying an exception message may notify and advise IT users that a file is about to deleted.

An important form of information to be communicated by exception messages are potential technical problems or systems failures. In these situations exception messages and the accompanying earcons should signal to the IT user the degree of hazard associated with the state of the system. The degree of hazard communicated by the exception message and accompanying earcon should match the degree of the level of hazard faced by the user, thus achieving hazard matching (Amer and Maris 2007; Hellier et al. 2000). In order to carry out hazard matching, systems designers must understand how the users of a system perceive the severity of hazard communicated by the various parameters of IT exception messages including the signal words and icons used, the color of the message, the screen size of the message, and the earcons that accompany the exception message. The severity of hazard a warning communicates is referred to as the “arousal strength” of the warning. Once the arousal strength of various parameters of an exception message is determined, these parameters can be manipulated to effect variations in the perceived hazard of the exception message. This allows exception messages to be matched to the appropriate hazardous situation or condition (Hellier et al. 2000).

Amer and Maris (2007) examined the effect of a number of signal words and signal icons that commonly occur in IT exception messages and their effect on the arousal strength of the message. Participants were shown a random order of exception messages containing several signal words and icons and combinations of signal words and icons in a controlled environment. The participants provided their perceptions of the severity of the IT hazard associated with each exception message on a ten-point Likert-type scale. The results indicate that different combinations of signal words and icons possess different levels of arousal strength and that signal words in combination with signal icons increase the arousal strength of an exception message. Their data will allow systems designers to accomplish hazard matching by aligning an exception message containing the appropriate signal word and icon with an IT or application control-related hazard.

The exception messages utilized by Amer and Maris (2007) did not include earcons and it is here that the current study picks up. The question addressed is how to design earcons to be included in IT exception messages that communicate various levels of arousal strength. This knowledge will further promote the design of exception messages to achieve hazard matching.

Musical Dissonance and Consonance

As noted above, the structured musical nature of earcons permits the creation of a wide variety of melodic and harmonic fragments using the dimensions of pitch, timbre, and/or rhythm. A well established musical construct that can be used in the development of musical earcons is the degree of musical

[1] The earcons that are used in Microsoft XP and Vista can be accessed from the “Sounds and Audio Devices” folder in the Windows Control Panel.

dissonance and consonance. Dissonance (consonance) describes the degree of unpleasantness (pleasantness) or disagreeableness (agreeableness) to the human ear that exists when certain musical pitches are heard together or within a short period of time. At a minimum two pitches are required to be sounded together or within a short period for some degree of dissonance or consonance to be experienced. When two pitches are sounded together or within a short period it is referred to as an interval. The musical distance between two notes of an interval is measured in semi-tones.[2] Some intervals are dissonant and others are consonant. It is well accepted that in the "just intonation" tuning system (a system based on harmonic ratios, which are approximated by the 12-tone equal temperament scale) the following intervals are considered dissonant:

Minor second – one semi-tone apart

Major seventh – eleven semi-tones apart

Augmented fourth (tri-tone) – six semi-tones apart

and the following intervals are considered consonant:

Octave – twelve semi-tones apart

Perfect fifth – seven semi-tones apart

Perfect fourth – five semi-tones apart

Aucouturier (2008) using the mathematical parameterization of Sethares (1993) further ranked the degree of dissonance and consonance of intervals in the order listed above such that the minor second is the most dissonant, followed by the major seventh, followed by the minor fifth. Similarly, the octave is the most consonant interval followed by the perfect fifth, followed by the perfect fourth.

An intuitive approach that can be used to design earcons that communicate high levels of hazard would be to exploit the notion of dissonance and consonance. Since humans find dissonance to be unpleasant earcons with high levels of dissonance should communicate higher degrees of arousal strength than earcons with high levels of consonance. Formally stated:

H1: Earcons formed of dissonant musical intervals will be perceived to communicate a higher level of arousal strength than earcons formed of consonant musical intervals.

III. RESEARCH DESIGN AND METHODOLOGY

Method

The data collection involved eliciting from participants a numerical rating on a ten-point scale of various earcons within the context of an IT exception message displayed on a computer screen. A fully randomized design was incorporated such that each participant viewed every earcon in random order and provided their perception as to the severity of the hazard communicated by the exception message.

Participants

The authors recruited 65 students from a large university to complete the elicitation exercise. The participants were comprised of upper division undergraduate accounting majors and were provided with a nominal level of extra course credit as an incentive to complete the exercise. Table 1 provides descriptive statistics of key information related to these participants. Data from Table 1 indicates that the participants were predominantly less than 35 years old and use computers two or more hours each day.

---

[2] A semi-tone is the distance between any two adjacent keys on a piano keyboard.

TABLE 1. Demographic Data of Participants

Category	Frequency
Age	
Less than 18 years	0
18 to 20 years	24
21 to 23 years	28
24 to 26 years	5
27 to 30 years	7
31 to 40 years	0
Over 40 years	1
Mean = 22.18, Std Dev = 4.16	
Gender	
Male	26
Female	39
Computer Use	
Less than an hour a day	1
One to two hours a day	9
More than two hours, but less than fours a day	20
Four to six hours a day	20
More than six hour, but less than eight hours a day	11
Eight to ten hours a day	1
More than ten hours a day	3

Procedure and Task

The task was administered using a computerized data collection program and was administered in a laboratory setting. All participants convened at a pre-established time in the computer lab with the authors present to provide instruction. Each participant sat at a computer within the lab and when instructed accessed the data collection program from a central server. The participants completed the task in its entirety during the sitting with the program randomly assigning the order of each exception message that was viewed by each participant. Each participant wore a set of headphones through which the earcons were sounded. Each participant adjusted the volume of the earcons to a comfortable level.

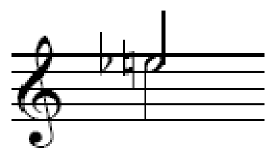
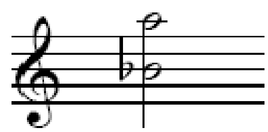
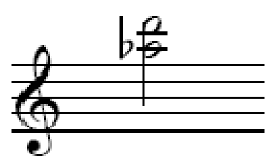
At the start of the exercise, the participants were instructed that the purpose of the study was to determine how people use and understand aural sounds that accompany exception messages. Next, the participants read through a scenario presented to them on screen that described a hypothetical computerized interaction. After reading the scenario, the participants answered three multiple-choice questions about the scenario. The multiple-choice questions were designed to ensure that the participants had attended to the contextual information presented in the scenario. The participants were not able to continue the exercise until they had answered the scenario-related questions correctly. Over ninety percent of the multiple choice questions were answered correctly on the first attempt indicating that the participants attended to the scenario.

The scenario described a common situation in which the participant was interacting over a computer network. A generic, yet very common scenario was presented to the participants to provide a reasonable context within which to assess the arousal strength of the earcons that were presented. Responses were not identifiable to any individual participant, but the participants' completion of the exercise was recorded by the authors in order to provide each participant with extra-credit course points. The participants provided a rating on a ten-point scale of the severity of hazard associated with different earcons.

Exception Message and Earcons

Figure 2 displays the elicitation screen used to capture the participant's responses. The common exception message shown in Figure 2 was created and held constant across all the earcons that were presented. Holding the visual characteristics of the exception message constant was important so the arousal strength of each earcon was isolated. The earcons that accompanied the exception message were generated using a music composition software program with a pitch range that is common to the earcons included in the Microsoft XP and Vista operating systems. Table 2 provides the list of the earcons evaluated for this study and is comprised of the dissonant and consonant intervals noted by Aucouturier (2008). The timbre and the musical instrument used to generate the earcons were held constant across all six musical intervals and was a grand piano.

TABLE 2. Earcons Used in the Experiment in Order of Most to Least Dissonant (Consonant)

Panel A – Dissonant Intervals	**Musical Notation**
Minor Second	
Major Seventh	
Augmented Fourth (Tri-tone)	

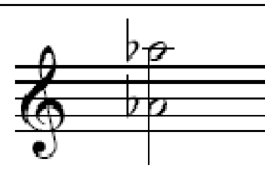
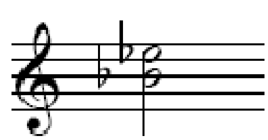
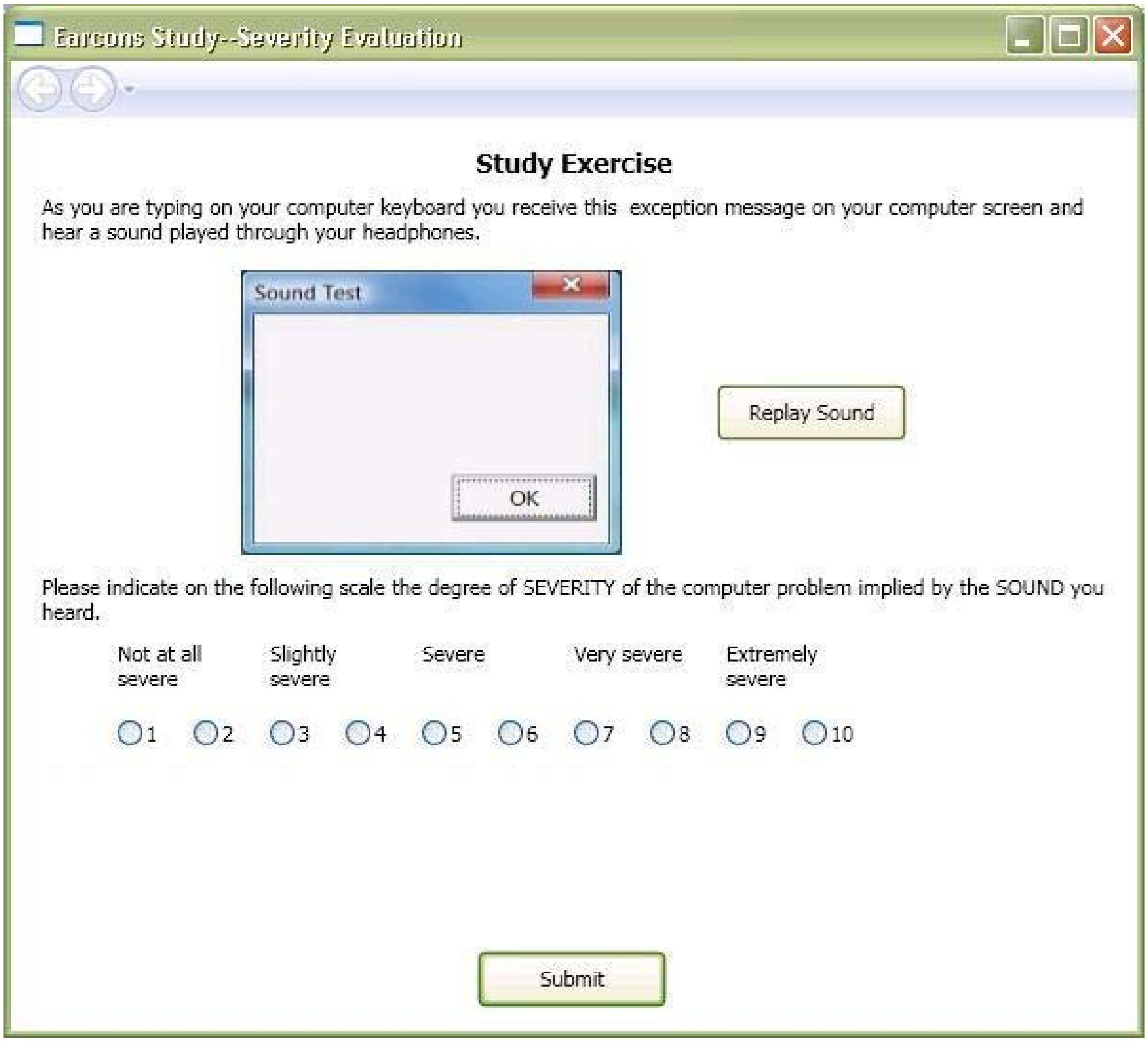
Panel B – Consonant Intervals	**Musical Notation**
Octave	
Perfect Fifth	
Perfect Fourth	

FIGURE 2. Example of the Elicitation Screen in the Computerizce Data Collection Instrument



IV. RESULTS

Table 3 lists the mean and standard deviations of the dependent variable for the six musical intervals. As can be seen from the data, there is little difference in the perceived level of hazard between the six musical intervals but for the interval of a major seventh. Based upon the theoretical discussion of musical dissonance and as specified in **H1**, one would expect that the level of perceived severity reported in Table 3 would be ordered such that the highest level of severity would be associated with the minor second interval and the lowest level to be associated with the octave. The intermediary levels of perceived severity would be ranked by the level of dissonance of the other intervals as defined by Aucouturier (2008). While the data of Table 3 does indicate a trend in the perceived level of severity consistent with the ranking of dissonance, the magnitude of the differences are not strong.

TABLE 3. Mean Values (Standard Deviations) of the Perceived Severity of the Computer Problem Communicated by Earcons

Musical Intervals	Perceived Severity
Minor Second	3.7 (2.1)
Major Seventh	4.4 (2.0)
Augmented Fourth (Tri-tone)	3.7 (1.9)
Perfect Fourth	3.5 (1.7)
Perfect Fifth	3.6 (1.7)
Octave	3.5 (1.9)

A pair-wise analysis of the data reveals that only the perceived hazard associated with the major 7^{th} interval is statistically different from the other musical intervals. While this result is consistent with **H1** it is the only interval that is so. Another result that is noteworthy is the high degree of variance associated with the data collected. An examination of the standard deviations of Table 2 indicates that the participants had relatively varied perceptions of perceived hazard. This high level of variance indicates that using earcons to communicate hazard may not result in consistency in communication as different computer users may perceive wide degrees of interpretation.

V. DISCUSSION

This manuscript examines earcons that frequently accompany exception messages that users of IT encounter during computer interactions. It is noted that exception messages within IT environments should communicate different levels of hazard in order to achieve "hazard matching." Hazard matching occurs when the severity of the hazard communicated by the exception message matches the level of hazard faced by the user.

Using the concept of musical dissonance it is hypothesized that earcons comprised of musical intervals with high levels of dissonance will be perceived to communicate higher levels of severity of a computer problem associated with an exception message. Such information could be used to design earcons that accompany exception messages to better achieve hazard matching. Results of an experiment carried out to examine the predictions partially support the hypothesis.

References

Amer, T. S. and J. M. B. Maris. 2007. Signal Words and Signal Icons in Application Control and Information Technology Exception Messages – Hazard Matching and Habituation Effects. *The Journal of Information Systems*. (21): 1 – 26.

Aucouturier, J.J. 2008. The hypothesis of self-organization for musical tuning systems. *Leonardo Music Journal*. (18): 63 – 69.

Blattner, M. M., D. A. Sumikawa and R. M. Greenberg. 1989. Earcons and icons: Their structure and common design principles. *Human- Computer Interaction*. (4): 11 – 44.

Brewster, S.A. (1998). Using Non-speech sounds to provide navigation cues. *ACM Transactions on Computer-Human Interaction*. (5): 224 – 259.

Garzonis, S., S. Jones, T. Jay, and E. O,Neill. 2009. Auditory icon and earcon mobile service notifications: Intuitiveness, learnability, memorability and preference. CHI 2009 – Multimodal Mobile Interaction April 8th, 2009 – Boston, MA, USA

Gaver, W. 1989. The SonicFinder: An interface that uses auditory icons. *Human-Computer Interaction*. (4): 67 – 94.

Lemmens, P. M. C. 2005. Using the major and minor mode to create affectively-charged earcons. *Proceedings of ICAD 05-Eleventh Meeting of the International Conference on Auditory Display*, Limerick, Ireland, July 6-9, 2005: 205 – 211.

Lemmens, P. M. C., A. De Haan, G. P. Van Galen, and R. G. J. Meulenboek. 2007. Emotionally charged earcons reveal affective congruency effects. *Ergonomics*. (50): 2017 – 2025.

Pramana, E. and Leung, Y.K. 1999. Exploring the learnability of structured earcons. In *Human-Computer Interaction: Ergonomics and User Interfaces. Proceedings of the 8th International Conference on Human-Computer Interaction*, H. Bullinger and J. Ziegler (Eds.) London: Erlbaum. 555 – 559.

Sethares, W.A. 1993. Local consonance and the relationship between timbre and scale. *Journal of the Acoustical Society of America*. (94): 1218 – 1228.