International Journal of Industrial Ergonomics 47 (2015) 117–123

Contents lists available at ScienceDirect

International Journal of Industrial Ergonomics

journal homepage: www.elsevier.com/locate/ergon

Applying signal detection theory to determine the ringtone volume of a mobile phone under ambient noise

Heekyung Moon [a], Sung H. Han [a,*], Jaemin Chun [b]

[a] Department of Industrial and Management Engineering, Pohang University of Science and Technology (POSTECH), San 31, Hyoja, Pohang 790-784, South Korea
[b] Human-Computer Interaction Institute, School of Computer Science, Carnegie Mellon University, 5000 Forbes Avenue, Pittsburgh, PA 15213-3891, USA

ARTICLE INFO

Article history:
Received 20 January 2014
Received in revised form
20 October 2014
Accepted 19 January 2015
Available online 7 February 2015

Keywords:
Signal detectability
Forced-choice tracking
Masked threshold
Human auditory perception

ABSTRACT

Although technologies for automatically adjusting the volume of mobile phone ringtones according to the ambient noise level have been developed, few studies have investigated the volume (dB) of the ringtone. This study suggested design recommendations for the ringtone volume under loud ambient noise. Based on signal detection theory, two-alternative forced-choice tracking was performed by thirty subjects to obtain hearing thresholds under noisy conditions. Six experimental conditions were examined: all combination of three pure tone frequencies (500 Hz, 1000 Hz, 4000 Hz) and two white noise levels (70 dB, 80 dB). The results showed that the ringtone volume should increase by 10–15 dB on average when the noise level increases from 70 dB to 80 dB. When adjusting the volume according to the ambient noise level, the volume should be changed differently according to the frequencies of a ringtone. The ringtone should be composed of low-frequency sounds under loud ambient noise because the subjects were very sensitive to the pure tone with frequency of 500 Hz. The results of this study could be used when developing design guidelines for the adaptive ringtone of a mobile phone. Moreover, designers can use this method to design other auditory signals such as notification and emergency alarms that have different chances of signal detectability.

Relevance to industry: The results of this study may provide useful information to designers who consider the volume and frequency of a ringtone when adjusting ringtone volume according to ambient noise level. Moreover, the method used in the study could also be widely used to design auditory signals of mobile devices other than mobile phones.

1. Introduction

1.1. Background

In a noisy environment, users need to adjust the volume of their mobile phones so that they can hear their ringtones. However, users set the volume of the ringtone once and seldom change it. Depending on the ambient noise level, two different problems can occur. In a noisy environment, users cannot hear their phone ringing; in a quiet place, they may be startled or irritated by a sudden loud ringtone.

Existing attempts to solve these problems are divided into two approaches. In the first approach, researchers determined the preferred volume of a ringtone. Yoo and Park (2000) investigated the subjective preference for various volumes. Users' preference on volumes was surveyed with regard to ringtone types, gender and location. Two representative locations were selected: a quiet office (25–50 dB) and a street (51–58 dB). The preference began to decrease from the volume of 52 dB in a quiet office and from 59 dB on a street. Although results suggested a subjectively-preferred volume, the experiment did not consider the case in which a user did not detect a phone ringing in a noisy situation. In the second approach, researchers developed technologies to automatically adjust the volume to a predetermined value that is sensitive to the ambient noise level (Siewiorek et al., 2003). The predetermined volumes were arbitrary values without considering detectability or users' preference.

To date, the estimates of the adequate volume of a ringtone have not considered human decision making. To suggest the volume from an ergonomic point of view, both the observer's ability to

* Corresponding author.
E-mail address: shan@postech.edu (S.H. Han).

http://dx.doi.org/10.1016/j.ergon.2015.01.002
0169-8141/

detect a stimulus (i.e., sensitivity) and individual tendency to respond (i.e., response bias) must be considered simultaneously.

1.2. Signal detection theory

Signal detection theory (SDT) can successfully explain the process that humans used to distinguish a signal from a noise. The case in which a user needs to detect a ringtone in a noisy environment can be thought of as a typical detection situation (Fig. 1).

The theory classifies two types of errors: *Miss* (observer does not detect a signal; i.e., user does not detect a ringtone) and *False alarm* (observer detects a nonexistent signal; i.e., user detects a ringtone when it does not occur) (Gescheider, 1997). The ringtone and the ambient noise correspond to the signal and the noise concepts of SDT, respectively.

Of these two situations, this study aimed at reducing the occurrence of *Miss*es by finding the volume of a ringtone that produces a specified probability of detection in the presence of loud noise. Reducing the *False alarm* rate is not the research object in this study because the noise distribution and the response criterion are unchanged even if the volume of a ringtone is changed (Fig. 1); i.e., a *False alarm* is not associated with the volume of a ringtone. In addition, a *False alarm* is not nearly as important as a *Miss* in real circumstances because people are not particularly concerned about detecting a nonexistent ringtone.

Two responses, *Hit* (i.e., correct detection of a ringtone) and *False alarm* rates, are characterized by pairs of parameters such as sensitivity and response bias. A sensitivity measure *d*' indicates the ability to discriminate between stimuli (Macmillan and Creelman, 1991); d' is the distance between the means of the two probability density functions (Fig. 1). A highly sensitive participant would have both the *Miss* rate and the *False alarm* rate close to 0. Response bias is defined as the observer's tendency to respond "yes" (i.e., a signal is present) or "no" (i.e., a signal is not present) (Kim et al., 2014). Based on their response bias, a participant establishes a response criterion at some point. An unbiased participant's response criterion would be located in halfway between the two distributions; a biased participant is conservative or liberal to respond "yes", the response criterion is higher or lower respectively. People can either be conservative or liberal in making a detection of a phone ringing. A person who is conservative is more prone to commit a *Miss* and less prone to commit a *False alarm* than is one who is Liberal, and vice versa.

1.3. Forced-choice tracking

To reduce *Miss*es, the adequate intensity of a ringtone can be determined by adaptive methods. Adaptive methods have been used to obtain the signal level that produces a specified *Hit* rate, $p(c)$, and the complementary probability that is equal to the *Miss* rate, $1 - p(c)$. The methods include yes–no procedure, forced-choice tracking, up-down transformed response, parameter estimation by sequential testing and maximum-likelihood methods (Gescheider, 1997).

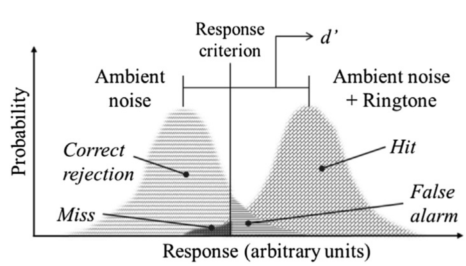

Fig. 1. Distribution of the ringtone of a mobile phone in a noisy environment based on the signal detection theory.

Forced-choice tracking is a widely-used psychophysical technique to obtain absolute or difference thresholds (Ulrich and Miller, 2004; Maurissen and Chrzan, 1989; Gatehouse and Davis, 1992). In each trial of forced-choice tracking, two or more intervals are presented and the observer reports which interval contains a signal. Depending on the observer's response, the intensity of the signal is changed. The forced-choice tracking is generally considered to yield better threshold estimates than other methods such as the yes–no procedure (Higgins et al., 1984; Macmillan and Creelman, 1991). In this study, the forced-choice tracking was selected for two primary reasons.

First, it provides a threshold that is not influenced by the observer's response bias (Gescheider, 1997). The goal of this study is to determine phone ringing circumstances that lead to neither conservative nor liberal setting of the criterion. If observers tend to be conservative or liberal to detect a signal, the result of this study might be confined to specific circumstances (Section 1.2). Forced-choice tracking forces people to choose one interval that contains a signal as opposed to giving a chance to respond "yes" conservatively or liberally. Thus, it could remove a bias that drives an individual to answer in a way that favors one response over another (Yeshurun et al., 2008).

Second, experimentally determined $p(c)$ values can be easily converted to a sensitivity measure d'. The sensitivity represents the ease with which a stimulus can be detected (Fig. 1). The converted value of d' can be compared with d' of other procedures such as yes–no and confidence rating which use different numbers of alternatives. Hacker and Ratcliff (1979) have calculated the value of d' for $p(c)$ values (from 0.1 to 0.99) according to various numbers of alternatives in the forced-choice tracking, for example, when $p(c) = 0.75$ and three alternatives are used, $d' = 1.43$.

Although many researchers have used the adaptive method to investigate hearing thresholds under noisy conditions, existing studies used a pure tone or a narrowband noise as the noise when obtaining the hearing threshold (Bacon and Moore, 1986; Kohlrausch, 1986; Laroche et al., 1992; Kidd and Feth, 1981; Zwicker and Zwicker, 1984; Zwicker and Henning, 1984). This choice of noise is not a good representation of reality because environmental noise in the real world includes complex sounds with various frequencies, so the threshold value for the ringtone volume should be obtained under white noise.

The primary objective of this study was to suggest recommendations for design of ringtone volume by obtaining the hearing threshold. Thus, we used the forced-choice tracking to consider human hearing ability with a decision-making process based on SDT. The hearing thresholds were obtained at various white noise levels and frequencies of a pure tone.

2. Methods

2.1. Subjects

Thirty subjects (15 male, 15 female; average age 22.2 (standard deviation: 2.3) years) participated in an experiment. They had hearing loss less than 25 dB, corresponding to the ISO standard definition of normal (ISO, 1999, 1990). None had a medical history or life habit that affects hearing ability.

To select subjects that had no any hearing problems, we conducted the subject selection process in two steps: screening questionnaire and pure tone audiometry.

1) The screening questionnaire was composed of two sections: medical history and life habits. In the medical history section,