Vibration Signaling in Mobile Devices for Emergency Alerting: A Study With Deaf Evaluators

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Received January 7, 2010; revisions received April 6, 2010; accepted April 19, 2010

In the United States, a nationwide Commercial Mobile Alert Service (CMAS) is being planned to alert cellular mobile device subscribers to emergencies occurring near the location of the mobile device. The plan specifies a unique audio attention signal as well as a unique vibration attention signal (for mobile devices set to vibrate) to identify that the incoming message pertains to an emergency. Ratings of vibration signals of varying lengths and patterns were obtained from 44 deaf users of mobile devices for the perceived effectiveness of the signal in getting their attention in an emergency situation. Longer signals received higher ratings than shorter ones, and three signals with temporal on–off patterns were rated significantly better than a constant vibration. The U.S. government’s recommended vibration signal for the CMAS, an important feature for access to emergency alerts by deaf persons, is supported by the results of the study.

Vibration signals for incoming mobile calls and messages are widely used as an alternative to ringtones in situations where the mobile device user does not wish to disturb others with an audible signal or simply due to personal preference. People who are deaf and many who are hard of hearing depend on vibration signals as the only accessible method of being alerted to calls and messages on a mobile device. A wireless emergency system that does not effectively alert them would put such users in harm’s way, as audio-based sources of immediate information, such as being told by someone nearby, or a public announcement in a building, would not likely be understood by people who cannot hear well. Thus, vibratory mobile device attention signals are particularly important to this population of people with disabilities.

In the United States, a Commercial Mobile Alert Service (CMAS) is being planned as an outcome of 2006 federal legislation (U.S. Congress, 2006). The CMAS is designed to alert cellular mobile device subscribers to events that are expected to cause “imminent threat to life or property” for people in the geographic area where they happen to be—if they are carrying a mobile device and it is turned on. A single national system is being planned for implementation by all U.S. mobile carriers, although participation by carriers is voluntary. The system will send government-initiated alerts by broadcasting a brief text message to mobile devices in a targeted geographic area (U.S. Federal Communications Commission [U.S. FCC], 2008).

The CMAS will be unique among methods of alerting in the United States in that (a) the user does not have to be watching television or listening to the radio, (b) the user does not need to sign up or register for the service (but can cancel the service if it is not wanted), and (c) the system targets mobile subscribers only in the geographic area of the event.

A Unique Attention Signal for Emergencies

As part of the plan for this service, a unique audio attention signal and a unique vibration attention signal are planned for mobile devices that are capable of producing the unique signals. (There is no U.S. government requirement that all mobile devices provide vibration.) People who can hear will be alerted to

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doi:10.1093/deafed/enq018
Advance Access publication on May 28, 2010
the emergency by the unique audio attention signal on their mobile devices or, if the mobile device is turned off, perhaps by the attention signal of someone else’s mobile device. For those who use vibration signals, a unique vibration would alert the individual who has the device set to vibrate, sometimes called “silent” mode, and who is wearing the device in contact with the body, for example, on a waistband or in a pocket.

The specific audio attention signal recommended to the FCC by an advisory committee, and then adopted by the FCC in its order (U.S. FCC, 2008), is a familiar sound used in the United States on broadcast television announcements from the Emergency Alert System. This audio signal consists of two tones, 853 and 960 Hz sine waves with a unique, discordant sound. The frequency range is relatively low, under 1000 Hz, and therefore should be discernible to people whose hearing loss is greatest in the high-frequency range, the most prevalent pattern of hearing loss at all age levels in the United States (Agrawal, Platz, & Niparko, 2008). (However, this assumption has yet to be tested.)

The advisory committee to the FCC recommended a cadence, or temporal pattern, for the signal to further help attract the attention of the user. This temporal pattern was adopted in the FCC order as “one long tone of two (2) seconds, followed by two short tones of one (1) second each, with a half (0.5) second interval between the tones. ... We will also require that the entire sequence be repeated twice with a half (0.5) second interval between repetitions” (U.S. FCC, 2008). The total length of the sequence as described is 12.5 s.

Purpose of the Study

Vibration signals for use in cellular mobile devices have been studied recently for value as tactile icons, or tactons (Brewster & Brown, 2004) for conveying information, either in combination with auditory signals (e.g., Chang & O’Sullivan, 2005; Chang et al., 2002; Hoggan, Crossan, Brewster, & Kaaresoja, 2009) or alone (Kaaresoja & Linjama, 2005; Quian, Kuber, & Sears, 2009). In addition, there has been recent study of haptic considerations in affective states for control of devices but not for receiving of haptic signals (Swindells, MacLean, Booth, & Meitner, 2007).

The purpose of this study is to understand user preferences for the particular application of emergency alerting because at present there is no unique vibration signal familiar to the general public for emergency alerting purposes. Because of the particular importance of vibration signals to people who are deaf and many who are hard of hearing, we conducted a study of a sample of deaf mobile device users who use text (e.g., e-mail, SMS, instant messaging) as their mode of mobile communication. This population is also of particular interest because they are heavy users of mobile devices, and thus very familiar with vibration signaling because they use it extensively. They might be considered “expert users” of vibration signals.

Our goal was to understand how mobile text devices are being used by deaf persons, for possible use in emergency management accessibility planning, and to study the opinions of mobile device users as to whether pattern and/or length of vibration signal make a difference in terms of their perceived efficacy in alerting someone to an emergency. Data were collected from students, faculty, and staff members at Gallaudet University, an institution of higher education for deaf and hard-of-hearing students in the United States.

Methods

The data collection sessions had two parts: (a) An interview about device use, and (b) acquisition of ratings by participants on a number of vibration patterns and lengths.

Interview

Interviews were conducted in American Sign Language (ASL) by a fluent signer. The written form of the questionnaire was also available to supplement the ASL conversation if the participant wished to view the choices in written English. The interview questions covered types of devices used at the time of the study, amount of time per day the device was used, the types of text communication used, the number of vibration patterns used, whether patterns were distinguishable
from one another, and respondents’ default vibration pattern for reception of mobile e-mail (which is the most frequent form of mobile text communication used by deaf people in the United States as evidenced by this sample).

Signal Evaluation

For the ratings portion of the study, vibratory temporal pattern and length of the vibratory signal were the independent variables. These were chosen because they have the potential to be easily varied within a mobile device by a manufacturer. In contrast, strength of the vibration was not treated as an independent variable, although it is of obvious interest because vibration strength variation (increasing or decreasing the amplitude of vibration, for example) is not as easily implemented within a mobile device and therefore could not be part of the government specification; rather, the level of perceived vibration strength for a given device would presumably be an evaluation criterion in a deaf person’s selection of a mobile device.

Dependent variables were (a) perceived similarity of each signal to the participant’s default vibration signal in use at the time of the study, on a four-point semantic scale from “very different” to “feels the same” (with the assumption that similar signals would be less desirable than ones that felt quite different); (b) participants’ ratings of each signal’s temporal pattern for getting one’s attention during emergency, on a five-point semantic scale from excellent to poor; and (c) participants’ rating of each signal’s length for getting one’s attention during an emergency, on a five-point semantic scale from excellent to poor.

The similarity or difference of the signal from the default vibration signal was evaluated because there are many situations in which a user may not wish to or may not be able to check every message, for example, while driving in some jurisdictions, or in a classroom. A unique signal, not easily overlooked, would identify that this message merits immediate attention. In addition, an unmistakably unique signal was determined by the advisory committee for CMAS to be in the public interest for hearing mobile users, and our study used this assumption as one other reason for asking participants to rate the signals for their similarity to their default signal, with higher value given in our study to the perceived difference based on subjective ratings.

Vibration stimuli were delivered on an HTC Dash mobile device, running Windows and capable of programmable vibration patterns. The dimensions of the device were $112 \times 64 \times 13$ mm. This device is similar in size to emerging devices at the time of the study that are likely to be more typical of devices when the CMAS is introduced (approximately 2012); for example, it is more similar in dimensions to an iPhone and a Droid (in 2010) than to the larger Sidekick of previous technology generations. (In general, larger devices provide stronger vibration.) Prior to data collection, project staff went to several mobile carrier stores and compared the strength of vibration signal in a variety of models to the test model; they determined that the vibration signal of the DASH was similar to the newer devices.

Participants held the device in one hand, with the back of the device against their palm. The normal-use position, such as a waistband or pocket, was not used because, during piloting, we found that a large variability in intensity would be experienced depending on the clothing worn by the participant, and it was expected that findings would be corrupted under these highly variable conditions. Measuring the variability imposed by the participants’ wardrobe on perception, and variability in perception on various parts of the body when clothed (e.g., pocket vs. waistband), was beyond our scope and capacity. But most importantly, our main research question was what consumers believe would be effective, given their extensive daily experience with receiving such signals. For this reason, after much consideration, we came to the conclusion that it was vital that our expert users be able to perceive the signals clearly and in a uniform way. By having them hold the device and concentrate on the signal, we were able to gather their considered judgments.

Four temporal vibration patterns were tested, each at three different lengths ($4 \times 3$), for a total of 12 different signals. This allowed us to obtain repeated measures at different lengths and patterns and to examine any interactions that might exist. The vibration
signals were delivered in quasi-random order. A practice item preceded collection of ratings.

The four patterns were

2. Even on–off: pattern of 500 ms on, 500 ms off.
3. Variable: pattern of 2 s on, 500 ms off, 300 ms on, 200 ms off, 300 ms on, 200 ms off, 1 s on. A period of 1.2 s off was inserted, and then the pattern was repeated in the case of medium and long sequences for this pattern.
4. Long/short: 1.6 s on, 200 ms on/off for six repetitions. A period of 700 ms was inserted and then the pattern repeated in the case of medium and long sequences for this pattern.

We found no literature on effective vibratory patterns for alerting and chose these four patterns with consideration of eliciting variance in responses, of current default signals on devices, and of the FCC’s recommendation. The lack of on–off pattern (constant) is common in mobile devices, although it is usually quite short in the default mode. Because it is already prevalent, it was included to determine whether, if this pattern were simply lengthened, if it would be evaluated well by study participants. Similarly, the even on–off pattern is a common one in mobile devices. Patterns 3 and 4 were designed to be quite different from the most common mobile signals and also different from one another. The variable pattern is most similar to the FCC recommendation. The fourth (long/short) pattern has an unusual buzzing feel to it in the six repetitions of the 200-ms signal.

The three lengths were

1. Short: ranging in length from 4.0 to 4.5 s.
2. Medium: ranging in length from 8.0 to 9.2 s.
3. Long: ranging in length from 13.0 to 13.9 s.

Data Analysis

Interview results were analyzed using descriptive statistics, depending on the type of data: frequencies, relative frequencies, ranges, medians, means, and in some cases standard deviations (SDs).

For the ratings data, to compare the main effects and interaction effects between the independent variables of Pattern and Length, a fully balanced analysis of variance (ANOVA) was used, with subjects as a blocking variable. This design is also called a repeated-measures design with two within-subjects variables and no between-subjects variables ($4 \times 3$). The three dependent variables measured on semantic distance or Likert-type scales were used in three separate ANOVAs. The length variable was treated as a nominal-scale variable.

Results

Characteristics of Respondents

The sample was composed of 44 deaf or hard-of-hearing individuals who use mobile devices for text communication and who use vibration signals for incoming messages. Participants ranged in age from 18 to 72 years, with a mean age of 30.8 years and median of 26.5. Fifty-two percent were female. When asked to identify themselves as deaf or hard of hearing, 38 (86%) said deaf and 6 (14%) said hard of hearing. The number of years of mobile device use reported by respondents ranged from 1 to 24 years, with a median of 7.5 years.

Mobile Device Use and Alerting Features

In addition to vibration, light (LED) on wireless devices can sometimes be used to indicate an incoming message—if the device is in line-of-sight at the time. Although 82% had lights for signaling on their devices, one third of those with the feature did not use it. The vast majority (90.9%) reported that they wore the mobile device on their bodies for sensing vibration (on a belt or in a pocket), with only 9.1% carrying it in a backpack. More than two thirds (68%) estimated wearing the mobile device 12 hr per day or more on average; the mean of respondents’ estimates was 14 hr per day.

All 44 respondents reported using vibration to alert them to incoming e-mail, 90% to SMS, and 66% to instant messaging. Respondents were asked to estimate the percentage of incoming messages they receive in these three media. Mean responses for each type were 60% e-mail, 20% instant messaging, and 20% SMS.
Most (71%) said they had the ability to choose vibration patterns for distinguishing the type or source of the messages, but slightly less than half of the sample (47.7%) made use of more than one pattern. Of those who did use more than one vibration alert, 90% reported that they could always or usually distinguish the patterns from each other.

The actual vibratory patterns in use for e-mail were measured by making an acoustic recording of the user’s personal device, placing a microphone against the device as it vibrated while receiving a message. The mean length of default (e-mail) vibration alert signal was 2.5 s. The range was quite large, from 0.42 to 14 s, with an SD of 2.5. The longest vibration (14 s) was vibration in sync with a musical ringtone. (The Sidekick, a popular device at this time among Gallaudet students, permits this feature.) The majority of devices (76.8%) vibrated just one or two times for the default alert (Table 1).

In Washington, DC, a free public alert service called DC Alerts allows subscribers to specify many variables in receiving e-mail alerts, including neighborhood, type of situation, and severity of alert. Gallaudet University also operates a free e-mail alert service for emergency and nonemergency messages about such things as interruptions or changes to the campus shuttle service. But only about one third of our respondents subscribed to e-mail news, weather, or emergency information services. Younger respondents were less likely to be subscribers to any alert service. Among those aged 25 years or younger, only 15% subscribed, whereas 50% of those 25 or older subscribed, a significant difference (likelihood ratio 6.285, df 1, p = .012).

Participants were asked during the interview, prior to evaluating signals, which of three variables was most important for possible emergency alerting through vibration on a mobile device: strength of the vibration, length, or pattern. The most prevalent choice was length (46% of respondents); the second most common choice was pattern (30%), and 25% indicated vibration strength as most important.

### Ratings of Vibration Signals

Tables 2–4 provide means, SDs, and significant effects for Similarity, Pattern, and Length.

**Similarity to default vibration.** Longer signals (across patterns) were rated as significantly more dissimilar from the participants’ default e-mail vibration signals than were shorter signals. Each of the three lengths is significantly higher than the adjacent level, suggesting a linear effect. Short signals were on average rated “somewhat different” (X̄ = 3.01), whereas long signals were on average rated better in terms of difference (X̄ = 3.37, with 3.0 being the rating for “somewhat different” and 4.0 being the value for “very different”). The even on–off pattern was rated as significantly more similar to the default pattern used on participants’ own mobile devices (X̄ = 2.79, SD = .957, p < .05), compared to other patterns.

**Ratings of effectiveness by pattern.** Patterned vibrations (across lengths) were rated significantly higher than a constant vibration signal. The even on–off pattern was rated highest, with a mean of 3.77, close to a rating of Good (Good = 4).
Ratings of effectiveness by length. Mean differences among the three lengths (across all patterns) were significant ($p < .05$), with longer signals being rated as most effective. On average, the longest signals were rated at 4.12, between Good and Excellent.

In summary, there were significant effects observed for length and pattern as well as an interaction between length and pattern on both ratings of length and pattern ($p < .05$). The combination of the even on–off pattern at the longest signal length generated the highest responses on length and pattern. This combination also elicited the lowest score on similarity rating (i.e., was perceived as relatively similar to an existing signal, when compared to others), suggesting that participants prefer a signal similar to what they are using. In general, signal length showed a linear trend, meaning that at the range tested, higher lengths generate higher response on length and pattern as well as at the interaction of length and pattern ($p < .05$).

Conclusions

Length of signal is an important consideration in vibratory emergency alerting, based on opinions of experienced mobile users who depend on vibration for their signaling needs. A patterned vibratory signal of sufficient length, in our experiment 13–14 s, should provide an alert that will be evaluated by deaf users as effective for alerting. Because all patterned signals were rated significantly better than the constant (no temporal pattern), a constant vibration should not be used. The even on–off pattern received the highest average ratings, but if used would need to be a long signal, on the order of 13–14 s. Shorter even on–off signals are used by many participants for their alerts to basic communications and would not be sufficiently distinctive.

Based on users’ opinions, the pattern recommended in the FCC report and order, or other distinctive patterns, are likely to be successful, as long as they are of sufficient length. The length of signal defined in the FCC order of 12.5 s is supported by these findings. Important to note is an asymptotic tendency at the longest signals, which may indicate a potential leveling off or even decrease in perceived effectiveness at lengths longer than 14 s. Thus, the FCC’s recommended length could be considered optimal, based on these findings.

Table 2 Similarity/difference from default pattern on own mobile device

<table>
<thead>
<tr>
<th>Length</th>
<th>Constant</th>
<th>Even on–off</th>
<th>Variable</th>
<th>Long/short</th>
<th>All</th>
</tr>
</thead>
<tbody>
<tr>
<td>Short</td>
<td>2.86 (1.05)</td>
<td>2.61 (0.92)</td>
<td>3.30 (0.823)</td>
<td>3.25 (0.751)</td>
<td>3.01b (0.929)</td>
</tr>
<tr>
<td>Medium</td>
<td>3.36 (0.838)</td>
<td>2.86 (0.930)</td>
<td>3.27 (0.788)</td>
<td>3.34 (0.834)</td>
<td>3.21b (0.866)</td>
</tr>
<tr>
<td>Long</td>
<td>3.66 (0.745)</td>
<td>2.89 (1.02)</td>
<td>3.341 (0.861)</td>
<td>3.59 (0.658)</td>
<td>3.37b (0.878)</td>
</tr>
<tr>
<td>All</td>
<td>3.30 (0.938)</td>
<td>2.79b (0.957)</td>
<td>3.30 (0.819)</td>
<td>3.39 (0.759)</td>
<td>3.20 (0.902)</td>
</tr>
</tbody>
</table>

Note. Higher scores indicate greater difference from the default vibration pattern of the user’s mobile device and are the more desirable ratings: 4 = Very Different. The baseline rating for this metric was a mean of 2.71 out of 4 ($SD = 1.112$). Numbers in boldface type indicate statistical significance ($p < .05$).

aEven on–off is significantly lower than all three other patterns.
bEach length is significantly higher than the adjacent level suggesting a linear effect.

Table 3 Rating of pattern for getting attention

<table>
<thead>
<tr>
<th>Length</th>
<th>Constant</th>
<th>Even on–off</th>
<th>Variable</th>
<th>Long/short</th>
<th>All</th>
</tr>
</thead>
<tbody>
<tr>
<td>Short</td>
<td>2.91 (1.34)</td>
<td>3.34 (1.06)</td>
<td>2.86 (1.11)</td>
<td>3.41 (1.25)</td>
<td>3.13b (1.21)</td>
</tr>
<tr>
<td>Medium</td>
<td>3.61 (1.46)</td>
<td>3.93 (1.925)</td>
<td>3.41 (0.996)</td>
<td>3.64 (1.1)</td>
<td>3.65b (1.15)</td>
</tr>
<tr>
<td>Long</td>
<td>3.70 (1.52)</td>
<td>4.05 (3.99)</td>
<td>3.95 (1.1)</td>
<td>3.93 (1.13)</td>
<td>3.91b (1.19)</td>
</tr>
<tr>
<td>All</td>
<td>3.41 (1.48)</td>
<td>3.77 (1.02)</td>
<td>3.41 (1.15)</td>
<td>3.66 (1.17)</td>
<td>3.563 (1.22)</td>
</tr>
</tbody>
</table>

Higher Scores indicate better propensity at getting attention: 5 = Excellent. The baseline rating for this metric was a mean of 2.16 ($SD = 1.238$). Numbers in boldface type indicate statistical significance ($p < .05$).

aEven on–off and variable are significantly different and variable and long/short are significantly different ($p < .05$).
bEach length is significantly higher than the adjacent level suggesting a linear effect.
The subjective methodology in which participants evaluated a clear signal is quite different than an objective study approximating very diverse normal-use conditions; in what we hope will be future field studies during CMAS testing, the results of the present evaluation could be validated by objective observational methods or logging, with a variety of clothing and distraction conditions.

An industry trend is toward smaller and slimmer mobile devices and, current models vibrate with less intensity than older, larger devices. In an ideally accessible world, vibration intensity, as well as pattern would be user controllable; in general, user control accommodates a range of preferences and needs. If the user could increase vibration strength, for example, it might increase perceptibility of an alert when the device is carried in a purse or backpack near the body but not body-worn. However, this type of control is unlikely to be a market trend, and the deaf and hard-of-hearing market alone could not support redesign of mass-market devices. Further, our observation is that Gallaudet students and staff are quickly migrating to more feature-rich small devices such as the iPhone, Droid, and smaller Blackberry models, perhaps indicating a willingness to trade off vibration strength for size and features. This is speculative, but based on our experience, we think it unlikely that vibration control will be a large advocacy issue whereas other, more pressing issues are in need of advocacy. Therefore, the manufacturing trend toward less-intense vibration, if it continues, supports the need for a longer signal to increase the likelihood that the emergency notification is received.

The greatest need for future research in alert signaling on mobile devices, we believe, is in the area of audio ring signals. Currently, ring signals do not use lower frequencies (e.g., 250–500 Hz) that might be more perceptible by hard-of-hearing people. Testing is needed to determine whether the FCC-recommended audio attention signal will be effective for people who use audio and not vibration alerts—although it is fortunate that vibration alerts are available as a backup for hard-of-hearing users.

Because younger deaf participants in our study tended not to sign up for free e-mail emergency alerts, the value of the CMAS, which will deliver alerts unless the user consciously decides to unsubscribe, is potentially of great benefit to deaf mobile device users in the United States.

### Funding

This work was supported by the National Institute on Disability and Rehabilitation Research, U.S. Department of Education (H133E04001) (Rehabilitation Engineering Research Center on Telecommunications Access). However, those contents do not necessarily represent the policy of the Department of Education, and you should not assume endorsement by the Federal Government of the United States.

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