Semantic Profiling:  
A Method for Relating Auditory Device Signals and Medical Messages

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The present study sought to relate auditory device signals and medical messages based upon shared semantic meaning. Thirty nine Intensive Care Unit (ICU) nurses evaluated thirty auditory signals and thirty written descriptions of medical messages using a common set of Semantic Differential rating scales. Auditory signals and medical messages were clustered based upon shared semantic meaning, which suggested a breakdown of medical messages into seven categories including both patient conditions as well as device information/feedback. Several categories of messages either had no related auditory signals or were related to auditory signals that are not specified in current standards.

INTRODUCTION

Current standards for auditory signals in medical devices (e.g., IEC, 2004) focus primarily on detectability and conveying various degrees of alarm urgency, but lack inherent meaning specifying the particular medical conditions they are intended to indicate. Although attempts have been made to leverage inherent verbal meaning in alarm design, verbal alarms present unique problems in the clinical environment (see Wilcox, 2011 for a review).

Osgood and his colleagues (Osgood, Tannenbaum and Suci, 1975) found that sensory experiences are rich in inherent semantic meaning that can be represented along three generic bipolar dimensions: Evaluation (good vs. bad), Potency (strong vs. weak) and Intensity (mild vs. intense). Kleiss (2008) applied the Semantic Differential method to characterizing perception of auditory device signals for consumer appliances and found evidence of four dimensions: three identified by Osgood et. al (1975), plus an additional dimension related to Novelty.

These four semantic dimensions describe the semantic character of auditory signals and reflect a form of inherent meaning. Semantic character in this sense is not specific to a particular event (i.e., multiple events may share similar semantic meaning), but it is specific to categories of semantically similar events. A semantic approach to defining auditory signals, therefore, has potential to convey inherent meaning for a category of medical messages, thus improving specificity at that level. The purpose of this study was to assess the semantic character of a variety of auditory signals and medical messages and to relate them based upon shared, inherent semantic meaning.

METHOD

Subjects

The subjects were thirty nine ICU nurses (mean age = 40.10 yrs., range = 23 yrs. to 64 yrs.). Mean years nursing experience was 12.97 yrs. (range = 1 yr. to 31 yrs.).

Auditory Signals

Thirty auditory signals were created by a professional sound designer including:

- An IEC Low-urgency alarm
- An IEC High-urgency alarm
- Versions of low, medium and high urgency IEC alarms created by varying the musical properties of timbre, attack, sustain, decay and release
- New creations of the sound designer

Medical Messages

Thirty medical messages typically communicated using auditory signals were sampled from documentation for ventilators, monitors and infusion pumps. Included were patient and device issues spanning a range of criticality.

Auditory Presentation

Auditory signals were presented using a Dell Latitude E6420 Laptop, standard sound card, Kramer Model VM-50HN Headphone Distributor and Sennheiser Model HD650 headphones.
Semantic Differential Rating Scales

Eighteen bipolar rating scales were created spanning a range of semantic content including Urgency, the primary attribute of alarm quality.

Rating Data Collection

Rating data were collected using an online data collection tool accessed via a laptop computer. Medical messages were displayed within the rating tool. Auditory signals were presented independently using the laptop computer described above.

Procedure

Data were collected in small groups of four or five subjects. The auditory signals and the medical messages were presented in separate blocks, half of the groups hearing auditory signals first. The auditory signals and the medical messages were presented in four quasi-counterbalanced orders across groups. Each sound and each message appeared equally often in the first, second, third and fourth quarter of the sequence according to a Latin Square arrangement. The order of stimuli in each quarter of the sequence was reversed for two of the four sequences.

All participants were allowed to complete their ratings for a given sound before the next sound in the sequence was presented.

RESULTS

Hierarchical Cluster Analysis

Rating data for auditory signals and messages were averaged across subjects and submitted to a Hierarchical Cluster Analysis using Unweighted Pair-group Average Linkage. Figure 1 shows the levels of dissimilarity at which clusters were joined at each step of the clustering process. Note that Dissimilarity grows increasingly large at ten and fewer clusters, arguing that the ten-cluster solution provides the optimal grouping of messages and auditory signals.

Figure 2 shows a dendrogram illustrating linkages among the ten clusters. Also shown are tallies for messages and auditory signals within each cluster. Note that three clusters contain no messages, indicating that the auditory signals associated with them would not be suitable for conveying medical messages.

Figure 1. Dissimilarity at which clusters were joined at each stage of the clustering process.

At the top of Figure 2 are three clusters containing messages related to device conditions. At the bottom of Figure 2 are four clusters containing messages related to patient conditions. Three clusters in the middle of Figure 2 contain no medical messages.

Principal Components Factor Analysis

Combined rating data for auditory signals and medical messages were also
submitted to a Principal Components Factor Analysis using the Varimax Rotation. In this analysis, data for each individual subject were retained as a separate row in the data file. Eigen values for the four-factor solution exceeded the critical value of 1.00, which explained 65.46% of the variance in ratings.

Table 1 shows bipolar attribute pairs sorted by factor loadings for each factor. Attributes that load highest on Factor 1 reflect variation in the Disturbing (Tense, Sick, and Assertive) quality of auditory signals and messages. High loadings for the attributes “Tense” and “Assertive” suggest that this factor corresponds to the Semantic Differential factor of Intensity.

Attributes that load highest on Factor 2 reflect variation in the Unusual (Rare, Unexpected, and Imaginative) quality of auditory signals and messages. This factor appears to correspond to the Semantic Differential factor of Novelty.

Attributes that load highest on Factor 3 reflect variation in the Elegant (Harmonious, Satisfying, and Calm) quality of auditory signals and messages. This factor corresponds to the Semantic Differential factor of Evaluation.

Attributes that load highest on Factor 4 reflect variation in the Precise (Trustworthy, Urgent, Firm, Distinct, and Strong) quality of auditory signals and messages. This factor appears to correspond to the Semantic Differential factor of Potency. Note that the attribute of Urgency, which is traditionally associated with alarm quality, loads on Factor 4.

Semantic Profiles. Factor scores for each sound and each medical message were averaged across subjects and are plotted for each factor in Figures 3 and 4. Medical messages are indicated by outline circles whereas auditory signals are indicated by solid dots. Lines are shown connecting the points for a representative object selected from each of the seven clusters containing medical messages shown in Figure 2. The lines define semantic profiles that visualize the semantic character of each cluster.

Profiles representing the four clusters of messages associated with patient conditions in Figure 3 reveal a characteristic U-shaped profile that is comparatively Disturbing, Typical, Unpolished and Precise. A slight exception is the profile for the sound associated with the message “High urgency alarm has been turned off”, which is notably more Unusual than other patient messages. This auditory signal sounds like heavy footsteps and its unique quality maps to the unique and infrequent nature of the medical message with which it is associated.

As the criticality of patient messages increases, profiles remain Unpolished, but become more Disturbing, Unusual and Precise (Urgent). Therefore, change in patient criticality is communicated by a combination of three semantic qualities of which the traditional alarm quality of being Urgent (Precise) is but one. To summarize, patient messages are characterized by the common semantic quality of being Unpolished whereas change in the criticality messages is communicated by change in three other semantic qualities.

Profiles for IEC Low-urgency and High-urgency auditory signals map to messages of low and medium criticality providing evidence of the effectiveness of these signals for communicating this difference in patient criticality. However, there is an extremely critical category of patient messages for which there are no associated auditory signals. This indicates a need for an additional auditory device signal that is even more Disturbing, more Unusual

<table>
<thead>
<tr>
<th>Attributes</th>
<th>F1</th>
<th>F2</th>
<th>F3</th>
<th>F4</th>
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<tr>
<td>Reassuring/Disturbing</td>
<td>0.74</td>
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<td>-0.03</td>
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<tr>
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<td>0.88</td>
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<tr>
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Profiles of Auditory Signals/Messages Representative of Four Clusters of Patient Messages

Figure 3. Profiles of Auditory Signals/Messages Representative of Patient Message.

Profiles of Auditory Signals/Messages Representative of Three Clusters of Device Messages

Figure 4. Profiles of Auditory Signals/Messages Representative of Device Messages.
and more Precise than current IEC standards used in this study.

Profiles for the three clusters associated with Device Info/Status are shown in Figure 4. Compared to Patient Messages, these profiles are universally more Elegant and tend to be more Reassuring and Vague. The profile for Non-critical Device Info is another message for which there are no associated auditory signals. An auditory signal fitting this profile would be highly Reassuring (harmonious), as Typical (common sounding) as the Low-urgency alarm sound, more Elegant (resolved) than current alarms and more Vague (softer attack) than all but the low-urgency alarm.

The profile for the cluster Device Info/Feedback tends to be comparatively neutral across factors, but slightly more Precise (harder attack) than the other two profiles. This profile maps to the comparatively neutral nature of the message being communicated.

The profile for Device Process Begun/Underway tends to be comparatively more Reassuring and Vague than Device Info/Feedback, serving the purpose of providing subtle but reassuring feedback.

Musical cues associated with each semantic dimension provide design guidance for creating new auditory signals to communicate various categories of medical messages. This is a particularly important issue in the case of the two categories of messages for which there were no associated auditory signals. According to the sound designer, auditory signals nearest the Disturbing end of Factor 1 are most discordant whereas auditory signals nearest the Reassuring end of Factor 1 are most harmonious. Auditory signals nearest the Typical end of Factor 2 sound most like traditional alarms whereas auditory signals nearest the Unusual end of Factor 2 are more Precise (sharper attack) than the current IEC High-urgency alarm standard. A fourth auditory signal associated with the message “high urgency alarm has been turned off” was not defined by IEC standards. This category of messages is highly unusual in that it provides feedback that a high-urgency alarm has been turned off. The absence of standard for this auditory signal represents another gap in current alarm standards.

Three other categories of medical messages related to device information and feedback. One related to general device information/feedback (i.e., a button has been pressed) and was characterized by relative neutrality across the four semantic dimensions reflecting the neutral quality of this type of message.

CONCLUSIONS

Auditory device signals and medical messages typically indicated using auditory signals can be characterized along four independent and inherently meaningful semantic dimensions. Nurses in the ICU environment conceive of seven categories of medical messages based upon perceived differences along each semantic dimension. Four categories relate to patient messages and share the common semantic characteristic of being Unpolished, or musically unresolved. As the criticality of patient messages increases, auditory signals become increasingly more Disturbing (discordant), Unusual and Precise (stronger Attack). Hence, patient criticality is communicated by a combination of three semantic qualities of which the traditional alarm quality of Urgency (associated with the semantic quality of being Precise) is but one. Therefore, the semantic conceptualization of patient messages should be expanded to include the constant quality of being Unpolished (musically unresolved) and the varying qualities of being Disturbing, Unusual and Precise (Urgent), which correlate with levels of criticality.

An IEC standard for a High-urgency alarm mapped to a cluster of medium-criticality patient messages suggesting that this standard is not sufficient to convey the highest degree of criticality perceived by nurses in this study. A cluster of Extreme High Criticality patient messages had no associated auditory signals suggesting a design gap for this category of messages. Knowledge of the musical properties associated with the various semantic dimensions provides design guidance for creating an auditory signal for this category. It would have the properties of being more Disturbing (discordant), more Unusual (unlike lower-criticality alarms) and more Precise (sharper attack) than the current IEC High-urgency alarm standard.

A fourth auditory signal associated with the message “high urgency alarm has been turned off” was not defined by IEC standards. This category of messages is highly unusual in that it provides feedback that a high-urgency alarm has been turned off. The absence of standard for this auditory signal represents another gap in current alarm standards.

Three other categories of medical messages related to device information and feedback. One related to general device information/feedback (i.e., a button has been pressed) and was characterized by relative neutrality across the four semantic dimensions reflecting the neutral quality of this type of message.
A second category of device messages corresponded to information indicating that a process (such as infusion of a drug or substance) has begun or is underway. It is characterized by being comparatively more Reassuring (harmonious), Unusual, Elegant (musically resolved) and Vague (softer attack) than general device information/feedback and serves the purpose of providing subtle reassurance of the status of an event.

A final category of device messages corresponded to low-priority status or feedback information and had no associated auditory signals. Once again, the semantic profile for these messages suggests musical properties that would be effective for conveying this semantic character. These include the semantic properties of being Reassuring (musically harmonious), Typical (sounding like conventional auditory device signals), somewhat Elegant (musically resolved) and somewhat Vague (soft attack).

To summarize, present results argue for a semantically rich characterization of auditory device signals for medical products in which each signal is described in reference to four semantic dimensions. Nurses in the ICU environment conceive of seven categories of medical messages characterized by differences in semantic profiles. Specific musical properties appear to be associated with three of the four semantic dimensions, providing design guidance for creating new auditory signals that fit specific semantic profiles. The semantic dimension of Novelty corresponds to the apparent typicality of auditory signals in the context of traditional ICU environments and reflects, in part, the frequency of occurrence of the signal in that environment.

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REFERENCES


