Earcon for Intermittent Information in Monitoring Environments

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Abstract

In this paper we discuss the first of a series of experiments evaluating earcons for critical care environments. We examine peoples' ability to monitor earcons conveying systolic and diastolic blood pressure while conducting a distractor task. The results showed that when a beacon is present prior to the earcon, participants' judgment of pitch and duration information improved. The results of the study also indicated presence of historical information in the earcon may interfere with participants' judgments. However, since participants felt more confident in their recall of previous values when the historical information was present, the results may reflect insufficient training.

Keywords

Auditory displays, Earcon, Beacons, Blood pressure, Memory

INTRODUCTION

The need for better auditory displays in many mission critical monitoring environments has been recognised for some time (Woods, 1995). Auditory displays that better convey information rather than directing attention have the potential to alleviate many issues associated with workload and vigilance common across mission critical environments. There has however, been little progress in developing new auditory systems in aviation and power systems and as yet we do not have any strong guidelines for their design (Sanderson et al., 2000). Approaches including sonifications, auditory icons and earcons may offer solutions that could increase situation awareness while reduced workload (Watson et al., 2004b).

In this work we focus on the development of blood pressure earcons for the operating theatre; however, the findings of the research program could be generalised to other intermittent scalable information sources. Earcons are described as "nonverbal audio messages that are used in the computer/user interface to provide information to the user about some computer object, operation or interaction" (Blattner et al., 1989). Earcons use combinations of short rhythmic motifs with variation in pitch, timbre and amplitude to help the listener identify the message (Brewster et al., 1994). Earcons have been used extensively in graphic user interfaces such as Microsoft Windows, although their use in representing more complex data than user alerts has not been broadly addressed. An example of a simple earcon can be found on many mobile phones when an SMS is received. Many listeners immediately identify the Morse message S_M_S as an alert that an SMS message has been received.

Morse code only uses the basic combinations of rhythm and duration to distinguish characters and words. Greater information can be encoded by adding sound dimensions that help distinguish what a message means. For example, one could add timbre identifiers to the SMS message that would help the receiver of the message distinguish who had sent the message; a brass timbre for family, organ timbre for friends and a violin timbre for work. Similarly, the importance of the message could be indicated by register; one octave for normal and another for high priority messages. The use of earcons to represent more complex data than user alerts may have many applications in mission critical environments and general human machine interfaces.

EARCONS FOR BLOOD PRESURE MONITORING

One mission critical environment where researchers are trying to provide better auditory displays is the operating theatre. Most of the proposed solutions have used sonification to represent low level physiological parameters that are or can be displayed as numeric readouts and visual plots (Watson et al., 2004a). A problem with some proposed sonifications is the inclusion of physiological parameters that are not continuously measured, such as blood pressure. The inclusion of intermittent measure parameters in a sonification have the potential to be dangerous, since the combination of the out-of-date information and other low level measurements may indicate an entirely different event to the one occurring or may just be confusing (Watson et al., 2004b).

A proposed solution is to use auditory displays to indicate the value of the intermittent measurement only when they occur (Watson et al., 2000). Three possible methods are: (1) converting the numeric values to synthetic speech, (2) auditory icons, and (3) earcons. Synthetic speech presents the problem that normal states are as distracting as abnormal states and the speech may interfere with the concentration of other operating theatre staff, such as the surgeons. The use of auditory icons is difficult for parameters that do not have a logical association and auditory icons are very limited for presenting scalable information. Earcons have the potential to convey both the type of parameter and the values for the parameter. Since earcons can be a set of simple rhythmic motifs, a well-designed hierarchy of relationships across earcons can allow for complex language to form, such as Morse code. Balancing the training and expertise required for people to recognise earcons within the attentional and workload demands of a domain will often limit the extent to which earcons can be implemented.

In developing blood pressure earcons for patient monitoring, the goal was to develop a set of earcons where the rule structure could be transferred to other physiological parameters. The earcons have been designed to provide information about systolic and diastolic (mean) blood pressure measured via non-invasive or invasive means. As non-invasive blood pressure measurements may be as infrequent as once every 5 minutes, we have also examined two previously untested aspects of auditory design: the concept of auditory beacons, and the presence of historical information. Kramer (1994) proposed peoples' judgments of sound that have scalable dimensional components, such as pitch, may be improve if they have an auditory reference to compare against. For example listeners' judgment of pitch for one earcon may be improved if they are given known values in a beacon immediately before the earcon. This is important in auditory displays because small changes in pitch might not be noticed from previously remembered pitch levels if there is some delay between hearing the two earcons. Historical information is encoded by playing the current measurement after the previous measurement and is intended to reduce the memory requirements when assessing the rate of change in blood pressure measurements.

EVALUATIONS OF EARCON BEACONS AND HISTORICAL INFORMATION

The three earcons investigated provide information about the patient's 'current' systolic and diastolic blood pressure (the first of these earcons referred to as C). The second earcon (BC) was presented with a 'beacon' before the systolic and diastolic measurements. The third earcon (BPC) also used the beacon, then provided information about the 'previous' measurements of blood pressure and finally information about the current systolic and diastolic blood pressure measurements. Twenty-four people participated in a within-subject repeated measures design to assess the earcons in a dual task paradigm. Participants attempted to monitor blood pressure change whilst completing a simple but also time consuming arithmetic task. A dual task paradigm was used for two reasons: first, to simulate similar repetitive tasks performed by anaesthetists that might distract from patient monitoring, and second, no reported earcon experiment had assessed the attentional issues of earcons associated with switching between unrelated tasks and the potential for the distracting task to interfere with memory. An unrelated task that requires the participant to process information and recall response from memory has the potential to interfere with their memory of past information from the earcons. There may also be an increase in errors in recognising the earcons if the participants have to refocus their attention from the visual arithmetic task to the auditory blood pressure monitoring task.

Participants received 45 minutes of training through a power point presentation built to familiarise the participants with everything that they would be required to do during the experiment. The earcon stimuli were composed of nine 10-minute scenario soundtracks in each condition: C, BC and BPC. These were composed of a backing track of respiratory and cardiac sonifications, with earcons placed at 2 minute intervals, with the first starting less than a minute into the soundtrack. Participants listened to three soundtracks per condition and the condition was counter balanced across participants. The arithmetic task was a program that presented simple sums such as (1+3 = 4); when a participant pressed the spacebar and the participant indicated whether the answer was true or false. Participants recorded their estimates of blood pressure on a nine-point scale for the previous and the current values of systolic and diastolic blood pressure. Responses were recorded on a fresh results sheet every time they heard the earcons to prevent participants referring to their previous answers. Participants also answered a series of questions throughout the experiment on their subjective experiences of the earcons.

RESULTS

Participants' results for the arithmetic task performance, earcon performance and questionnaire responses were analysed using a series of ANOVAS and linear contrasts. A one-way ANOVA was computed for total correct answers in the arithmetic task, which was not significant $F(2,22) = 0.42$, $MSe = 53.59$, $p = 0.959$. There were no significant differences for arithmetic task performance between earcon conditions.

Participants were very accurate at the blood pressure plotting task with all three earcons C, BC and BPC (Figure 1). A three-way within-subjects factorial ANOVA was conducted on the plotting results. The independent variables were earcon type, blood pressure measure and blood pressure history. The dependent variable was average absolute deviation of scores from actual blood pressure values. Earcon type had three levels (C, BC and BPC) corresponding to the three earcon designs. Blood pressure measure had two levels, systolic and diastolic, whilst blood pressure history also had two levels, current and previous. Four analyses were conducted in addition to testing the main effect of earcon type. The linear contrasts conducted are specified in Table 1.

Table 1: Participants' judgement for systolic and diastolic blood pressure. Scores are the mean error away from the correct score on the nine-point rating scale.

	Transformed Variable	Sum of Squares	df	Mean Square	F	Sig.
L1	BC vs. BPC at prior	2.282	1	2.282	2.779	.109
L2	BC vs. BPC at current	8.027	1	8.027	40.036	.000
L3	C vs. BC at prior	2.947	1	2.947	5.294	.031
L4	C vs. BC at current	1.373	1	1.373	4.431	.046

A series of eight subjective questionnaire responses about the effects of the earcon on participants' perceived workload, memory requirements and task performance were analysed using ANOVAs. Only Question 5: "How much effort was required to remember the previous blood pressure values?" found significant differences between the earcons. The results for the three conditions were compared with a one way ANOVA and were significant $F(1,23) = 10.97$, $MSe = 49.80$, $p = 0.000$. The ANOVA was followed up with pairwise comparisons, with the BPC condition significantly easier to remember than the C condition, Mean difference = -1.623, $MSe = 0.461$, $p = 0.02$. The BPC condition was also significantly easier to remember than the BC condition, Mean difference = -1.246, $MSe = 0.341$, $p = 0.01$. The BC condition was not significantly easier to remember than the C condition, Mean difference = -0.377, $MSe = 0.257$, $p = 0.157$.

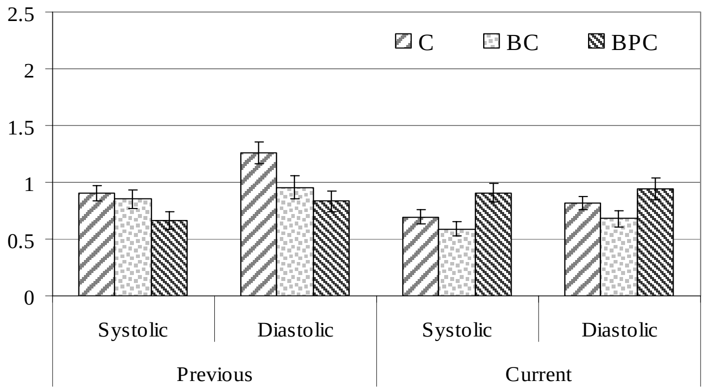

Figure 1: Participants' judgment error for systolic and diastolic blood pressure. Scores are the mean error away from the correct score on the nine-point rating scale. Error bars indicate SEM.

Although the results of Question 6, "How hard did you have to concentrate to interpret the Earcon?" indicated no significant differences between the three earcons the response did indicate that participants had to concentrate to interpret the earcons. $F(2,22) = 0.455$, $MSe = 1.588$, $p = 0.637$. On a 7-point Likert-type scale, participants' responses indicated that they considered the three earcons required considerable concentration: C = 4.51, BC = 4.71 and BPC = 4.81.

DISCUSSION

Participants performed better at monitoring the current systolic and diastolic blood pressure when previous measurements of blood pressure were absent in the earcon; however, the questionnaire results indicated they considered it easier to identify previous measurement of blood pressure when the information was present. Since the participants also indicated they had to concentrate to interpret all three earcon, the benefits of historical information in the earcons may only become apparent when the people are well practiced.

The presence of a beacon in the earcon was beneficial in the BC condition. However, because participants' judgments in the BPC condition was significantly worse than their performance in the BC, it may be that as earcon length and complexity increases, the usefulness of the beacon declines. More research is also required to ascertain why the beacon helps people to report values more accurately. The beacon may help people calibrate the pitch difference across the nine levels of the blood pressure earcons, or alternatively, the beacon might act as a signal for participants to reorientate their attention from the visual modality to the auditory modality. We are currently investigating the use of a single auditory alert (which cannot be used for pitch judgements) prior to the blood pressure earcon that will only assist participants' judgments by giving them time to reorientate their attention to the earcons. The alert finding will be presented in comparison with those of the beacon at a later date.

Most participants reported that they had to concentrate to interpret the earcons, indicating that further practice is needed in the use of the auditory displays before they can be used to support attention in the operating theatre. It is expected that the results of the study are likely to underestimate the potential of earcons, due to the short amount of training. Early studies of Morse code training show that participants improve substantially with continual training and exposure, particularly in situations where multiple tasks need to be accomplished at once (Bryan & Harter, 1897). Although the complexity of the blood pressure earcons is not as great as the characters found in Morse code, concepts such as relative pitch still may take people some time to master.

People's judgments of the earcon during the experiment were much better than expected; however, the real value of the earcon can only be judged when compared to experts' performance with current visual displays. We are therefore conducting similar dual task experiments to compare participants' performance with the earcons against traditional visual representations of systolic and diastolic blood pressure. Other factors that support better blood pressure earcon recognition – including the use of a musical scale, varying octave ranges and the use of timbre to distinguish them from existing alarms – are yet to be examined.

CONCLUSIONS

Participants' accuracy at judging earcons that involve a level of pitch judgments was very encouraging, suggesting that earcons can convey scalar information. Further work is required to establish whether the effectiveness of using beacons for earcons are through facilitating scalar comparisons of pitch or timbre, or by acting as a prompt to switch attention to the information following the beacon. Other issues that need to be addressed before effective guidelines on earcon design can be developed include training requirements, the interaction between earcons and other auditory displays, and cross modality issues that may arise from people having to combine the earcon information with information in the visual modality.

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