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Using Earcons to Monitor Multiple Patients

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Clinicians often monitor the status of multiple patients who are out of the clinician's field of view. An auditory display that intermittently conveys the vital signs of these patients through an earpiece may help clinicians detect problems with one or more patients. The auditory display could convey the status of multiple patients by representing a sequence of patients as a sequence of *earcons*. Earcons convey information through short, abstract tones that are played intermittently (Brewster, Wright, & Edwards, 1992).

In recent work, Janata and Edwards (2013) created a set of 500 ms earcons that conveyed the oxygen saturation (SpO_2) and heart rate (HR) levels of individual neonates. Their earcons used variations in tremolo (the amount of corrugation of the sound) to represent HR and variations in timbre (the amount of brightness of the sound) to represent SpO_2. Their set of 25 earcons conveyed 5 levels of HR and SpO_2; 'Very High', 'High', 'Normal', 'Low' and 'Very Low' for each variable. The earcons proved moderately successful for conveying the status of individual patients.

We applied Janata and Edwards' (2013) earcons to multiple-patient monitoring by placing the earcons in a sequence, each earcon representing the status of one patient. The intention was that the sequence of earcons would be played at regular intervals, such as every one to two minutes, to reassure the clinician that all is well or to alert them to early signs of deterioration in one or more patients. We refer to this as a cycling earcon display. The sequence begins with a reference tone, alerting and reminding the listener of the earcon sound associated with normal HR and SpO_2 values. The reference tone is followed by a sequence of earcons separated by intervals of less than 1 s (one earcon for each patient). In our study we used only the 'Very High', 'Normal', and 'Very Low' earcons from the Janata and Edwards set to maximize the discriminability of the earcons.

Two experiments were conducted with non-clinical participants to test the feasibility of the cycling earcon display for multiple-patient monitoring. We anticipated that accuracy in both experiments would be limited by auditory working memory (Baddeley, 2012).

In Experiment 1, participants monitored 1, 5 or 9 simulated patients in a sequence amongst which there were either 1, 2 or 3 patients with abnormal values of HR and SpO_2. Participants were asked to report the HR and SpO_2 levels for the patients with abnormal values. The inter-stimulus interval (ISI) between earcons was 150 ms. Results showed that the number of patients in the sequence did not affect identification accuracy, but identification accuracy decreased as the number of patients with abnormal values increased from 1 (Mdn = 97%) to 3 (Mdn = 67%), $p < .001$. Accuracy may have been lower in conditions with more than one abnormal patient, because an ISI of 150 ms may not have allowed participants enough time to encode the sounds in working memory.

In Experiment 2 we increased the ISI to see if accuracy could be improved. The number of patients in a sequence was fixed to 5 and the ISI was either 150 or 800 ms. Again, identification accuracy decreased as the number of abnormal patients increased from 1 to 3, $p < .001$, but accuracy was significantly better with an ISI of 800 ms (*Mdn* = 89%) compared to an ISI of 150 ms (*Mdn* = 83%), $p < .001$. Accordingly, having more time to encode the sounds may have helped participants to retain the information.

Results from the two experiments suggest that with further testing and design, multiple patients could be monitored through a cycling earcon display. Although clinical monitoring loads of 3 abnormal patients amongst 9 patients are rare, our aim was to test the boundaries of participants' ability to monitor this type of cycling earcon display. In future work, we will test improved cycling displays with clinician participants experiencing clinically relevant situations.

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