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Translational Science

Effectiveness of enhanced pulse oximetry sonifications for conveying oxygen saturation ranges: a laboratory comparison of five auditory displays

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Abstract

Background: Anaesthetists monitor auditory information about a patient's vital signs in an environment that can be noisy and while performing other cognitively demanding tasks. It can be difficult to identify oxygen saturation (Sp_{O_2}) values using existing pulse oximeter auditory displays (sonifications).

Methods: In a laboratory setting, we compared the ability of non-clinician participants to detect transitions into and out of an Sp_{O_2} target range using five different sonifications while they performed a secondary distractor arithmetic task in the presence of background noise. The control sonification was based on the auditory display of current pulse oximeters and comprised a variable pitch with an alarm. The four experimental conditions included an Alarm Only condition, a Variable pitch only condition, and two conditions using sonifications enhanced with additional sound dimensions. Accuracy to detect Sp_{O_2} target transitions was the primary outcome.

Results: We found that participants using the two sonifications enhanced with the additional sound dimensions of tremolo and brightness were significantly more accurate (83 and 96%, respectively) at detecting transitions to and from a target Sp_{O_2} range than participants using a pitch only sonification plus alarms (57%) as implemented in current pulse oximeters.

Conclusions: Enhanced sonifications are more informative than conventional sonification. The implication is that they might allow anaesthetists to judge better when desaturation decreases below, or returns to, a target range.

Key words: auditory perception; data display; patient monitoring; pulse oximetry

The pulse oximeter auditory display indicates a patient's heart rate, rhythm, and oxygen saturation (Sp_{O_2}) value when the visual display is not readily available; for example, when an anaesthetist is engaged in other visually demanding tasks or when the visual display is obscured. However, clinicians have difficulty identifying specific Sp_{O_2} values from the auditory tone alone.[1] Furthermore, as task load and noise increase, anaesthetists are less able to distinguish changes in Sp_{O_2} values using only the auditory display.[2] The situation is exacerbated by the fact that the acoustic properties of current pulse oximeters are not standardized across makes and models.[3]

Recent research shows that listeners can distinguish designated Sp_{O_2} ranges and transitions into and out of a target range

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Editor's key points

- Sp_{O_2} levels are commonly monitored by sound alterations, also known as sonifications.
- The auditory identification of Sp_{O_2} levels may however be difficult in a noisy and demanding environment.
- In this study, Sp_{O_2} sonifications were enhanced with tremolo or brightness as additional sound dimensions to improve accurate detection of Sp_{O_2} transitions.
- Enhancement of Sp_{O_2} sonifications resulted in a more accurate recognition of transitions in Sp_{O_2} levels, and a better detection of desaturation in a noisy environment.

more accurately with an enhanced auditory display (sonification) than with a variable pitch only sonification.[4–6] The enhanced sonifications in these studies comprised variable pitch with the addition of other sound characteristics in non-target ranges. A limitation of these studies was that participants had no other tasks apart from judging Sp_{O_2} ranges and detecting transitions into and out of the target range, whereas during surgery anaesthetists perform many tasks in addition to monitoring a patient's state. Another limitation was that the research was conducted in a quiet room without background noise, whereas noise levels in the operating theatre average from 51 to 75 dB[7] and can reach values >120 dB.[8]

In this study, we compared participants' ability to distinguish transitions into and out of a Sp_{O_2} target range using five different sonifications while performing a distractor task and in the presence of background noise. We predicted that participants using sonifications enhanced with additional sound dimensions would detect Sp_{O_2} transitions into and out of a predefined target range more accurately than participants using a conventional variable-pitch-only sonification.

Methods

The study was approved by the School of Psychology, The University of Queensland (UQ; ethical clearance number 16-PSYCH-PHD-17_TS). Participants signed an informed consent form agreeing to participate. All data were de-identified.

Power analysis

We conducted a power analysis based on a pilot study that tested 20 participants' accuracy to detect transitions into and out of a target range using a variable pitch plus alarm sonification and an enhanced variable pitch for multiple patient monitoring sonification. The sample size required to obtain significance for four contrasts at $\alpha = 0.05$ was ≥ 14 participants in each condition. We set our number at 20 participants per condition.

Participants

Participants were UQ undergraduate students who were not clinicians or clinical trainees. They received either course credit or a $20 gift voucher. Participants were excluded if (i) they reported hearing abnormalities, or (ii) they had participated in another of our auditory experiments. We allocated each participant to a condition using a block randomization process to ensure equal proportions of musically trained participants in each condition. Musical training was defined as having >1 yr of formal music training.[9]

Design

The experiment was a between-subjects design with one independent variable (sonification) with five conditions: (i) Alarm Only (AO); (ii) Variable pitch (Vp); (iii) Variable pitch plus Alarm (Vp+A); (iv) Enhanced Variable pitch for Single patient monitoring (EVp:S); and (v) Enhanced Variable pitch for Multiple patient monitoring (EVp:M).

In all conditions, there were 30 trials of 60 s duration. In each trial, participants monitored the assigned sonification while Sp_{O_2} ranged over one or more predefined ranges: Target (100–97%), Low (96–90%), or Critical (89–80%). Heart rate was steady at 72 beats min^{-1}, to correspond to an average adult heart rate. No visual readout of Sp_{O_2} range or absolute value was present during trials. Participants performed a forced-pace distractor task (arithmetic) throughout each trial.

The primary outcome measure was participants' accuracy at detecting transitions from the Target to the Low range, or vice versa. Secondary outcome measures were as follows: (i) average latency of detecting transitions between the Target and Low ranges, or vice versa; (ii) accuracy at identifying the Sp_{O_2} range (Target, Low, or Critical) at the end of each trial; (iii) accuracy at identifying absolute Sp_{O_2} percentage value (80–100%, plus or minus 1%) at the end of each trial; (iv) accuracy at classifying arithmetic expressions as true or false; (v) average latency of classifying arithmetic expressions as true or false; and (vi) number of arithmetic questions answered. Secondary outcome measures were exploratory in nature.

Apparatus and stimuli

The experiment was conducted on a MacBook Air laptop computer with a 13-inch screen (Apple Computer, Cupertino, CA, USA). Trials were presented using custom software written in Java (Java SE Development Kit, Version jdk1.8.0_40.jdk, Oracle, Redwood Shores, CA, USA). Participants responded using a mouse and keyboard. Sonifications were presented through two active 40 W studio monitor speakers (Behringer MS40, Kirchardt, Germany). The background noise was played through an iPad Mini (Apple Computer).

Sonification conditions

The sound characteristics of the sonifications are in Table 1 (see Supplementary Material to hear the sonifications used). In the Alarm Only (AO) condition, there was no pulse oximetry sound, but an alarm sounded [IEC-Medium-General alarm (IEC-60601-1-8)] [10] as soon as Sp_{O_2} entered the Critical range from the Low range and every 15 s thereafter that Sp_{O_2} remained in the Critical range. If the trial started with Sp_{O_2} in the Critical range, the alarm first sounded on the second or third pulse tone. This condition corresponds to a typical use of pulse oximetry in the intensive care unit, with the variable pitch tone silenced to reduce noise levels, but with alarms enabled.

The Variable pitch (Vp) pulse tones were pure sine wave functions ranging logarithmically from 150 Hz at 80% Sp_{O_2} to 950 Hz at 100% Sp_{O_2}; each 1% change in Sp_{O_2} corresponded to a 1.84% change in frequency.[3] Each tone was 150 ms in duration and included 10 ms fade-in and 10 ms fade-out to eliminate acoustic artifacts. This condition corresponds to use of pulse oximetry sounds when alarm limits are set very wide or alarms have been silenced.