RESPIRATORY SONIFICATION HELPS ANAESTHETISTS TIMESHARE PATIENT MONITORING WITH OTHER TASKS

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ABSTRACT

We explored the effectiveness of continuous auditory displays, or "sonifications", for conveying information about an anaesthetised patient's respiratory state. A dual-task experiment showed that sonification helps anaesthetists maintain high levels of awareness of patient state and at the same time perform other tasks more effectively than when relying upon visual monitoring of patient state. In summary, sonification of patient physiology beyond traditional pulse oximetry appears a viable and useful adjunct when monitoring patient state.

KEYWORDS: Sonification, auditory displays, patient monitoring systems, cognitive engineering.

1. INTRODUCTION

Human factors researchers have been aware for some time that auditory alarm system pose severe attentional problems for human operators in many different work domains. Auditory alarms sometimes intrude when they are uninformative and fail to capture attention when they are needed. Reflecting this, most auditory anaesthesia alarms are either ignored, considered a nuisance, or serve simply as a reminder of a previously known state of affairs (Watson, Russell, & Sanderson, 1999, 2000a; Watson, Sanderson & Russell, 2000b; Seagull & Sanderson, 2001; in press, Xiao, Mackenzie, Seagull, & Jaberi, 2000). In this paper we report on an investigation into how sonification—the representation of data relations in sound relations—might continuously inform anaesthetists about a patient's state, lessening reliance on visual displays or auditory alarms that sound when parameter limits are reached.

The most useful information display in the operating room (OR) is the pulse oximetry system—a sonification in which the rate and spacing of a series of beeps gives information about heart rate (HR) and rhythm, and the pitch of the beeps gives information about arterial oxygen saturation (SpO2). Of 1256 anaesthesia incidents in the Australian Incident Monitoring Study (AIMS: Runciman, Webb, Barker, & Currie, 1993), pulse oximetry detected the largest proportion (27%) of evolving incidents. Interestingly, capnography (measurement of expired or end-tidal carbon dioxide, CO_2) detected the second largest proportion (24%) of evolving incidents and if other respiratory variables such as respiration rate (RR) and tidal (breath) volume (Vt) are included, 39% of evolving incidents would be detected by respiratory monitors. Because of interactions between parameters, the information presented in pulse oximetry plus a respiratory sonification could detect over 90% of evolving incidents in the operating theatre. However, there is no respiratory sonification in regular clinical use. Could a sonification be built for respiration that could work alongside pulse oximetry?

Experimental research is emerging on the sonification of respiratory variables and other variables beyond those sonified in pulse oximetry. Fitch and Kramer (1994) asked participants to monitor eight physiological variables mapped into two independent auditory streams. Participants using sonification alone identified problems faster and more accurately than participants using sonification plus a visual display, or a visual display alone. However, their mapping of physiological parameters to sound dimensions appeared somewhat arbitrary. With a simpler and more intuitive sonification, Loeb and Fitch (2000) recently found better performance for sonification plus a visual display rather than for sonification or visual display alone. However, results measured participants' ability to recognise specific events they had been trained to identify, rather than any abnormality. Moreover, we do not know if sonifications beyond pulse oximetry can be safely monitored out of focal awareness so that significant state changes capture attention from other tasks.

In an ongoing research program we have been exploring the possibility for a respiratory-based sonification to work in conjunction with current pulse oximetry systems to reduce dependence on auditory limit-based alarms (Watson, et al., 1999; 2000a, 2000b, 2001). Such a sonification could deliver some of the advantages of pulse oximetry to the equally important respiratory domain. In one study, Watson and Sanderson (2001) compared the effectiveness of three candidate respiratory sonifications at supporting participants' judgments about whether respiratory parameters were normal or abnormal and whether there were any directional changes in any parameter. We established the following.

- With a minimal level of familiarization, participants can monitor respiratory status using certain respiratory sonifications as well as they can monitor cardiovascular status using pulse oximetry.

The most effective respiratory sonification from the first study was then tested in a second study in which the patient monitoring performance of anaesthetists was compared with that of tertiary-educated non-anaesthetists.

- Anaesthetists performed significantly better than non-anaesthetists at detecting respiratory abnormalities and changes.
- Anaesthetists' ability to detect respiratory abnormalities and changes with the respiratory sonification was at least as good if not better than their ability to detect cardiovascular abnormalities and changes with pulse oximetry.

1.1 Testing Timesharing Performance Across Modalities

In the above studies, participants were able to give their full attention to the pulse oximetry and respiratory sonifications. The real advantage of sonification, however, lies in the way it frees the listener to perform visual and manual tasks while still monitoring information auditorily. During the preparation and induction phase of an operation, anaesthetists should be able to perform manual tasks such as inserting intravenous and arterial lines or performing intubation without having to continuously look up or turn around—often from awkward positions—to read patient vital signs from a visual monitor. During the maintenance phase of the operation, the anaesthetist should be able to chart patient vital signs, perform drug calculations, draw up drugs, etc., while maintaining continual awareness of the patient's condition without the workload of reading the monitor. Anaesthetists should then be able to intervene *before* alarms go off signaling that a parameter has reached its limit.

We briefly report the results of a study that examines patient monitoring performance when participants must carry out a cognitively loading task at the same time. Patient monitoring is performed with sonification only, visual support only, or with both sonification and visual support. The hypothesis was as follows:

> *When participants perform a cognitively-loading primary task, they will be able to monitor patient physiological status more effectively when patient data is sonified than when it is visually supported.*

2. METHOD

2.1 Participants

There were 21 participants. Eleven were senior anaesthesia consultants and registrars at two major metropolitan teaching and research hospitals. Ten were tertiary-educated information technology postgraduates with no training in physiology.

2.2 Stimuli and procedure

Secondary task. The patient monitoring used anaesthesia scenarios produced from an anaesthesia simulation (the Body™ simulation from Advanced Simulation Corporation). SCHIL's *Arbiter* experimental environment provided the visual and auditory interface for the Body™ (Watson et al., 1999; 2000a; 2000b). The visual interface is shown in Figure 1, showing HR, O2, RR, Vt, and CO2. The respiration sonification used a pure tone and mapped inhalation and exhalation to the upper and lower note of a musical third. RR was represented by a direct temporal mapping of inhalation and exhalation, Vt was represented by sound intensity, CO2 was represented by a frequency modulation of the inhalation/exhalation minor third. The flow rate of gas in the breathing circuit was mapped to sound intensity which indicated Vt.

Figure 1: The Arbiter interface showing HR, O2, RR, Vt and ETCO2.

The secondary task was presented in one of three formats, varied within-subjects:

- Sonification alone (S condition). No patient information appeared or could be called up on the computer screen. It could only be heard.
- Visualization alone (V condition). Physiological readouts were not continually present. Participants had to touch ("query") the relevant part of the screen to see the current value for five seconds (the so-called "withholding" procedure).
- Sonification plus Visualization (SV condition). Patient information could be seen (by querying the screen) or heard (with the sonification).

When queried at semi-regular intervals about a particular parameter (HR, O2, RR, Vt or CO2) participants reported whether it was abnormally high, normal, or abnormally low, and whether it was increasing, steady, or decreasing.

Primary task. We constructed a very conservative primary task to establish baseline levels of timesharing performance. Participants were required to make true/false judgments about simple arithmetic expressions that appeared at the bottom of the computer screen (see Figure 1) with a new expression occurring every 10 seconds. The 10-second arrival rate of arithmetic problems gave participants in the V and SV conditions enough time to query all parameters, if they wanted to, before the next arithmetic expression appeared. Although sonification is intended to provide information where visual information is unavailable or inconvenient, in this first experiment we set up the best possible conditions for the visual display to succeed. If the S condition leads to superior performance even under such good conditions for the visual display, then the S condition's superiority would very convincing. If the S condition leads to the same level of performance as for the V condition, however, then at least we know that sonification does not support worse performance than a visual display does and still may have advantages as yet undemonstrated. It would then be assumed that if the time between arithmetic problems were to be reduced in subsequent experiments, the S condition and probably also the SV conditions would show increasingly effective monitoring performance relative to the V condition. The results of this experiment will therefore provide a conservative baseline comparison between the three conditions.

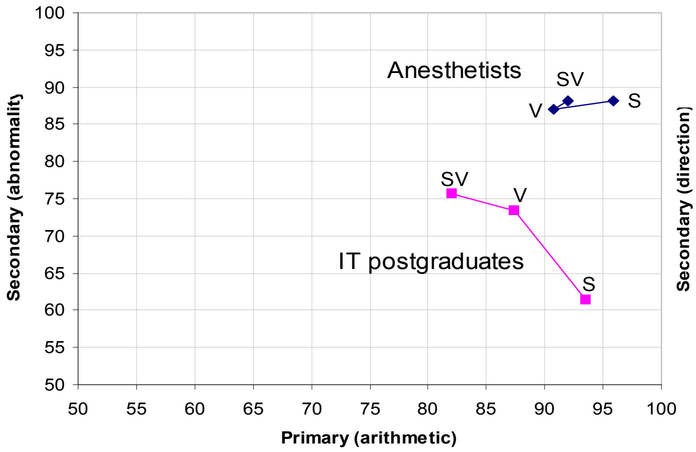
3. RESULTS

Primary (arithmetic) task performance was analysed using a between-within subjects ANOVA. Results are shown in Table 1 and on the x axis of Figure 2. Anaesthetists performed better than IT postgraduates. Arithmetic performance was most accurate in the S condition, followed by V and SV. A Newman-Keuls analysis of the three modality means showed that responding in the S condition was significantly more accurate than in either the V or the SV conditions.

Primary (arithmetic) task performance							
		Group		Modality		Group x Modality	
Accuracy		**		***		**ns**	
Secondary (monitoring) task performance							
	Group	Modality	Parameter	G x M	G x P	M x P	G x M x P
Abnormal	***	**	***	**	**	**	**ns**
Directional	***	**ns**	***	**ns**	**ns**	**ns**	**ns**
Querying	**ns**	**ns**	***	**ns**	**ns**	†	**ns**

Table 1: Results of ANOVAs for experiment. † = 0.1>p>0.05, * = p<0.05, ** = p<0.01, *** = p<0.001.

Secondary (monitoring) task performance showed that Anaesthetists were much better than IT postgraduates at reporting *abnormalities*. Performance was worst with the S condition, leading to a modality effect, but only because of IT postgraduates' poor performance. Anaesthetists judged abnormalities equally well across all three modalities whereas IT postgraduates did particularly poorly when faced with S alone, leading to an effect of Modality and an interaction of Modality with Group. Vt showed worst performance and HR best, but the poorer performance with Vt was much reduced for Anaesthetists compared with the IT postgraduates. Secondary (monitoring) task performance showed that Anaesthetists were much better than IT postgraduates at reporting *direction of change*. Worst performance was for Vt.



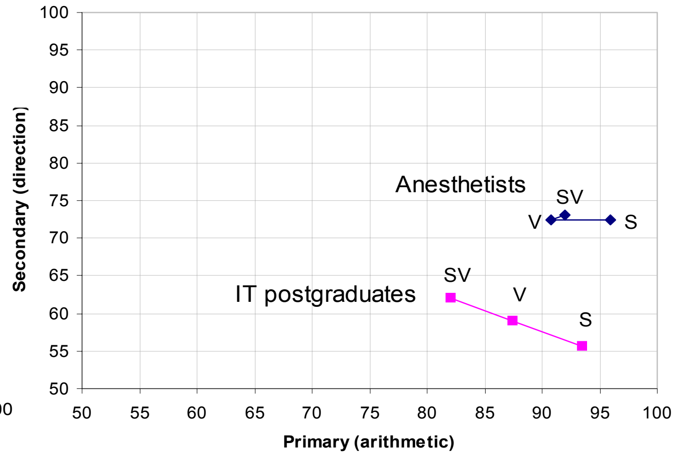


Figure 2: Primary task (arithmetic) performance and secondary task (patient monitoring) judgments of physiological abnormality (left figure) or direction of physiological change (right figure).

Querying the visual display for parameter values was compared across conditions SV and V. Querying was unaffected by Group or Modality, but tended to happen less for pulse oximetry variables HR and O2 than for respiratory variables RR, Vt and CO2. Interestingly, Newman-Keuls analyses revealed there was a significant drop in querying in condition SV compared with V, but only for Anaesthetists, and then only for HR and O2, the most familiar pulse oximetry sonifications. With further experience, and with performance feedback, participants would probably develop greater self-confidence in their ability to extract information from sonification and reduce visual monitoring for respiratory parameters as well.

4. DISCUSSION

Overall, sonification revealed its advantages differently than we expected. We expected primary (arithmetic) task performance would stay the same whereas patient monitoring performance would vary, depending on whether it was supported by visual, sonification or combined displays. Instead, primary (arithmetic) performance varied as the modality of the secondary (monitoring) task was changed. As would be expected from their professional training, anaesthetists maintained very high levels of patient monitoring across all three monitoring modalities and performed better with sonification on the primary (arithmetic) task than with either condition that offered visual information. IT postgraduates also performed the primary (arithmetic) task best when patient monitoring was sonified, but at the cost of low patient monitoring performance. As soon as visual information was added, primary (arithmetic) performance went down and patient status judgments went up. IT postgraduates' lack of physiological knowledge may have lead to poor association and grasp of the semantic meaning of the sonification and therefore there were trade-offs between the primary (arithmetic) task and patient monitoring tasks.

Trade-offs between sonified patient monitoring parameter performance and primary task performance have also been noted in a study examining response times under high visual primary task workloads (Seagull, Wickens & Loeb, 2001). Seagull et al. (2001) conveyed six physiological parameter using three sonification and visual conditions. The study examined the performance of participants with no medical training and therefore the trade-off between the patient monitoring task and the primary target-tracking task closely reflect our findings for the IT postgraduate.

In our own work it was found that when anaesthetists carry out a distracting task at the same time as monitoring, as is often the case in the operating room, sonification helps them time-share. However, instead of boosting monitoring performance while a distracting task is done, sonification allowed anaesthetists' monitoring performance to be sustained at already high levels while performance at the distracting improves. In ongoing research we are graduating the level of difficulty of the primary task and expect to see greater differences emerge across conditions in the quality of patient monitoring as the primary task becomes more distracting, increasingly favoring sonification.

In summary, sonification may help anesthetists maintain high levels of awareness of patient state and at the same time do other tasks more effectively than when relying upon visual monitoring of patient state alone. Further work is required to identify any benefits such sonifications may offer to other members of the operating theatre.

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