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The impact of workload on the ability to localize audible alarms

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ABSTRACT

Very little is known about people's ability to localize sound under varying workload conditions, though it would be expected that increasing workload should degrade performance. A set of eight auditory clinical alarms already known to have relatively high localizability (the ease with which their location is identified) when tested alone were tested in six conditions where workload was varied. Participants were required to indicate the location of a series of alarms emanating at random from one of eight speaker locations. Additionally, they were asked to read, carry out mental arithmetic tasks, be exposed to typical ICU noise, or carry out either the reading task or the mental arithmetic task in ICU noise. Performance in the localizability task was best in the control condition (no secondary task) and worst in those tasks which involved both a secondary task and noise. The data does therefore demonstrate the typical pattern of increasing workload affecting a primary task in an area where there is little data. In addition, the data demonstrates that performance in the control condition results in a missed alarm on one in ten occurrences, whereas performance in the heaviest workload conditions results in a missed alarm on every fourth occurrence. This finding has implications for the understanding of both 'inattentional deafness' and 'alarm fatigue' in clinical environments.

1. Introduction

The many problems associated with clinical alarms are well documented in the literature. Key among the problems is the issue of 'alarm fatigue' – an often-noted, but not clearly understood, description of a problem which stems from a combination of high false alarm rates, meaningless or difficult-to-understand alarms, noise, excessive monitoring, and other issues surrounding good practice (Cvach, 2012; Deb and Claudio, 2015; Drew et al., 2014; Kristensen et al., 2017; Sendelbach and Funk, 2013; Welch, 2011; Whalen et al., 2014). Not least of the problems associated with audible alarm signals specifically is that their design is very far from ideal, with alarm signals typically found to be difficult to learn and remember (Atyeo and Sanderson, 2015; Edworthy et al., 2014; Lacherez et al., 2007; Sanderson et al., 2006; Wee and Sanderson, 2008). The reason for this is that clinical alarms are often tone-like, akin to short melodies, largely abstract (where the sounds have little or no relation to their referents) and are often very similar to one another, thus proving to be difficult to learn and retain.

Many accounts of missed alarms exist in the reporting literature, and fatalities and other serious incidents are often attributed to 'alarm fatigue' because the nurse or clinician did not hear, or reports not having heard, the relevant alarm (e.g. Drew et al., 2014). The reason for missing the alarm is sometimes cited as being associated with the nurse's state at the time – for example, they may have been tired, at the end of a shift, may have been overwhelmed by alarms, may have some hearing loss etc. Just as likely, the reason for the missed alarm has something to do with the relationship between the alarm and the nurse in psychoacoustic, cognitive, or broader human factors, terms. The four most obvious explanations would be that the particular alarm is usually false, and so the nurse has tuned it out (this is commonly thought of as the key element of alarm fatigue as the relationship between false alarm rate and response is well documented (Bliss et al., 1995; Bliss and Dunn, 2000)); the alarm could have been masked by other alarms or noise and so be inaudible to the nurse (Hasanain et al., 2017; Patterson, 1982; Laroche et al., 1991); the alarm could be difficult to localize and hence failed to draw attention to the particular location of the problem (Alali, 2011; Catchpole et al., 2004; Edworthy et al., 2017; Vaillancourt et al., 2013); or the nurse was busy attending to other tasks (i.e. multitasking) and so her attention was diverted from alarm sounds to other tasks, an auditory phenomenon often referred to as 'inattentional deafnes' (Dalton and Fraenkel, 2012; Dehais et al., 2014; Macdonald and Lavie, 2011; Raveh and Lavie, 2015; Murphy and Greene, 2015). Here, if a person is doing more than one task, then they have to divide their mental resources between them and therefore this may exceed that person's capacity both within and across sensory modalities (Wickens,

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1991). Inattentional deafness probably lies within the domain of problems which ensue when workload is high, or where cognitive capacity is stressed in one way or another.

Many factors conspire to confuse the hearer about the nature of alarm; what it is, where it is coming from, whether there was an alarm or not (as the clinician might have been doing one or two other things at the same time and so is unsure), the physical and mental state of the hearer, and other factors. The design of the alarm could in principle help the hearer, though this does not always happen. As well as being difficult to learn and retain, the localizability of alarms could also be improved. Although the mechanisms concerned with localizability by the ear and brain are complex (Blauert, 1997) we do know that by and large sounds are easier to localize if they are harmonically complex, making white noise the most localizable sound. By contrast, clinical alarms tend to be harmonically very simple, meaning that their localizability will not have been optimized. There are many clinical environments (for example a multibed ICU or recovery room, which could have up to 16 beds) where automatic and accurate localization (through the operation of mechanisms of the ear and the brain) would be of benefit.

In an earlier study (Edworthy et al., 2017) we designed five sets of audible alarms using different design principles, and showed that the learnability and localizability (except for localizability in one case, which was expected and predicted) of our new designs outperformed the audible alarms currently supporting an international clinical device safety standard (IEC 60601-1-8, IEC (2012)). In the localizability study (Edworthy et al., 2017, Experiment 2), the mean localizability accuracy for the best-performing alarm set, the ‘auditory icons plus ident’ set, was just above 0.9 (out of 1). For the worst-performing set, the current IEC sounds, overall localization accuracy was 0.74 (out of 1). This means that in the IEC condition participants were mislocalizing a quarter of the alarms (one alarm in every four) whereas in the best-performing condition, they were mislocalizing only one in 10 alarms. This is meaningful at a practical level.

In Edworthy et al., (2017) participants were simply asked to identify from which of eight speakers an alarm was transmitted in each trial. In the study here, we increase the difficulty of the task by adding some secondary tasks, and noise, and gauge their effects on localizability.

The practical focus of this project is to update the audible alarms currently recommended by IEC 60601-1-8. On the basis of the work described in Edworthy et al. (2017), the ‘auditory icon plus ident’ set of alarms has been selected for further testing and development through consultation and agreement with the body charged with recommending the specific details of the updates proposed for 2019, when the new version of the standard is published (this is an IEC alarms joint working party). The study described here represents one arm of this further testing, exploring the effect of workload and noise on people's ability to localize this set of alarms, using the localization paradigm used in Edworthy et al. (2017). As workload affects ability on most other tasks, including auditory tasks, we would expect it to influence people's ability to localize an alarm sound, so we would expect that a participant's localization ability should be reduced when they are performing one or more secondary tasks when compared with a simple localization task. In our study we introduce either one or two secondary tasks. Most simply, we would expect the addition of secondary tasks to degrade performance in our localization task. There are few studies which consider this issue so our work adds to knowledge in this area as well as providing further testing of the alarms aimed at the update of the relevant standard.

2. Method

2.1. Participants

Two hundred and seven participants were recruited to participate in this study (175 women, 32 men, $M_{age} = 20.78$, age range: 18–50 years). Most were psychology undergraduates at Plymouth University. Recruitment took place using the Plymouth Psychology participation pool and participants received one participation point in exchange for completing the 30-min study. All participants stated that they had normal, or corrected to normal, hearing. Details of participants' age and gender were also obtained (See Table 1). No other demographic information was recorded.

Table 1
Number of participants in each condition and age range for each condition (Cond = Condition).

Condition	Number of participants	Age range (SD)
Control (Cond 1)	23	18-50 (5.15)
ICU Noise (Cond 2)	34	18-42 (4.92)
Reading (Cond 3)	33	18-46 (5.44)
Mental arithmetic (Cond 4)	49	18-50 (6.50)
Reading plus noise (Cond 5)	35	18-35 (4.08)
Mental arithmetic plus noise (Cond 6)	33	18-44 (4.60)

3. Materials and design

3.1. Summary

The overall design of the study was 6 (task, between-subjects) x 8 speakers (within-subjects) x 8 alarm sounds (within-subjects). Each participant was required to detect and respond to the occurrence of alarms spaced around them in a circle, while performing a secondary task, either in noise or in quiet.

3.2. Primary task (alarm localization)

A set of eight auditory alarms previously tested for learnability and localizability (with no secondary tasks) were used as the stimuli, and can be seen in Table 2 (Edworthy et al., 2017). The sounds were normalised for loudness and were presented at approximately 60–63 dB (A), measured through 3 10-s bursts of sound at 70 inches from each of the speakers. The sounds varied from 2 to 3 s in length. Each of the sounds consisted of an auditory icon (as listed in Table 3) plus an ’ident’, which was the general alarm indicated in Table 2, an abstract sound of fixed length. For the general alarm, only the ident was used.

Eight identical tripods were placed around a central point (where the participant was to be seated), each with a small speaker attached to it (EasyAcc mini portable model LX-839, output 3 W), in the format

Table 2
Auditory icon alarms used in the study. Each alarm (other than the General alarm) was played simultaneously with the general alarm, in an ‘auditory icon plus ident’ design, the general alarm serving as the ident (from Edworthy et al., 2017).

Function of Alarm	Alarm Characteristics
General	A burst of three regularly spaced pulses each of 75 ms in length, followed by a gap of 0.15 s, followed by two further pulses of 75 ms on a fixed pitch (c c c – c c) The whole 5-pulse unit then repeated; then the whole 10-pulse unit repeated after approximately 1 s
Power down	The sound of a hedge trimmer failing to start
Cardiovascular	A ‘heartbeat’ sound with no discernible frequency. Six pulses formed from 3 2-pulse units indicating 3 heartbeats
Drug Administration	The sound of a continuously rattling ‘pillbox’
Perfusion	A ‘water bubbling’ sound, 2 pulses each approximating 1.5 s in length
Oxygen	The sound of an aerosol, 4 pulses each spaced 600 ms apart
Ventilation	The sound of a single deep breath out
Temperature	The sound of ‘frying on a stove top’