Comparisons of Evacuation Efficiency and Pre-travel Activity Times in Response to a Sounder and Two Different Voice Alarm Messages

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Summary. Previous studies (Bellamy and Geter, 1990, BRE Report BR 172; Proulx and Sime, 1991, Fire Safety Science, 3rd International Symposium, pp. 843–852; Sime, 1998, Human Behaviour in Fire, Proceedings of the First International Symposium, pp. 299–308; Purser and Bensilum, 2001, Safety Science 38, pp. 157–182) have indicated that recorded voice alarm messages can be more efficient than sounders in motivating occupants to evacuate buildings, and that they produce shorter pre-travel activity (*pre-movement*) times (PTAT), sometimes by a wide margin. More recently, with increased use of voice alarms and other voice announcements, people may have become less responsive. For this study, monitored evacuations using voice alarms were conducted in a shopping centre, a theatre and a large office building (Purser and Bensilum, 2001, Safety Science 38, pp. 157–182). An experimental study was then set up in a university teaching room under hidden video surveillance, in order to examine responsiveness to different alarm systems (including a sounder, long and short voice messages) and provide PTAT data. The findings from both the monitored evacuations and the experimental study were that voice alarms provided more reliable and shorter PTAT response times than sounders, especially in "awake and unfamiliar" behavioural scenarios. Occupants tended to listen to the full voice message and sometimes the first repeat before starting to travel. The short voice message produced a shorter but less reliable PTAT response. Group interactions had a major effect on response behaviours and times.

1 Introduction

Evacuation time, has two major phases: Pre-travel activity time (PTAT; also known as pre-movement time or pre-evacuation time)—the time between that when each occupant becomes aware of an emergency and that when they begin to move towards the exits), and Travel time (the time required for occupants to travel to a place of safety) [1–3]. These are additive for each individual so:

$$\Delta t_{\text{evac}} = \Delta t_{\text{PTAT}} + \Delta t_{\text{trav}}. \tag{1}$$

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For occupant populations, PTAT can be expressed in terms of a variable period between the fire alarm and that when the first few occupants begin to travel, followed by a distribution of travel times (approximately log-normal) for the remainder of the population. PTAT and travel distributions interact, as some occupants are in their PTAT phases while others are in their travel phase.

$$\Delta t_{\mathrm{PTAT}} = \Delta t_{\mathrm{PTAT(first\ occupants)}} + \Delta t_{\mathrm{PTAT(occupant\ distribution)}}. \quad (2)$$

For each occupant PTAT has two main behavioural components:

- ***Recognition***—which starts with the cue or alarm and ends with the first response to the alarm. During this period occupants continue with the activities engaged before the alarm.
- ***Response***—which starts with the first behavioural response to the alarm and ends when each occupant begins to travel towards an exit. During this period occupants engage in a range of behaviours such as investigation, warning others, and collecting belongings or family members before entering their travel phase.

During evacuation experiments it is possible to measure the recognition and response times and their distributions.

PTAT is affected by many variables related to individual occupant and group behavioural characteristics, the nature of the occupancy, the building and its systems. Some of the more important include:

- Alertness (sleeping/waking)
- Occupants familiar or unfamiliar with building and systems
- Fire safety management: extent to which trained staff/floor wardens encourage evacuation
- Warnings: sounder, pre-recorded voice alarm or directed Personal Address
- Activities: commitment to ongoing activities
- Training and previous experience
- Group interactions: extent to which evacuation of a group is influenced by individuals (especially staff trained in emergency evacuation procedures)

Two studies reported in 1190 and 1991 [4, 5] demonstrated that recorded voice alarm messages can be more efficient than sounders in motivating occupants to evacuate buildings, and that they produced shorter PTATs. In one study [4] for which subjects attended a London office building and were left to complete a "job application" form, very large time differences were obtained between 10 subjects who were subjected to a voice alarm (triggering evacuation within 0.5 minutes) and a matched group subjected to a fire alarm bell, who took up to 11 minutes to leave the room. In another study in an underground metro station [5], similar differences were obtained between a voice alarm (1.15 minutes response time) and a sounder (9.0 minutes).

The work reported here consists mainly of an experimental study set up in a university teaching room under video surveillance, in order to examine responsiveness to different alarm systems (including a sounder, long and short voice messages) and provide PTAT data. The experimental study design was based on the results of previous monitored evacuation studies, including two cases using voice alarms: in a shopping centre and a large office building [1]. Some of the key findings from the shopping centre, and office building are therefore also presented here, but described in more detail in reference [1].

2 Methods

The two monitored evacuations were unannounced. The shopping centre restaurant contained customers, who were basically unfamiliar with the building and systems, and the restaurant staff. The alarm started with a loud sounder lasting 9 seconds, followed after a 10 second silence by a voice message lasting 13 seconds. The message was as follows:

> *"Attention please, attention please. This is a public security announcement. Circumstances make it necessary for us to evacuate the building immediately. Please collect your hand-luggage and make your way to the nearest exit and leave the building. Please do not re-enter the building until advised to do so."*

The video record was used to measure the PTAT recognition and response times and travel times to the restaurant exits for each of 11 restaurant customers, and to observe the behaviour and PTAT times of the staff.

The multi-storey office case included video surveillance of a single meeting room on the third floor, containing 12 occupants unfamiliar with the building and its systems. Measurements were made of PTAT recognition and response times, and travel times to the room exit. For this building the alarm consisted of a sounder warning signal lasting 4 seconds followed by the following voice message lasting 13 seconds (total 17 seconds): "Attention please, attention please; this is an emergency, please leave the building by the nearest available exit. Do not use the lifts".

For the experimental study in the university teaching room, 59 participants mostly unfamiliar with the building and systems were recruited ostensibly to take part in a series of psychological creativity tests for which a £5 fee was offered. They were randomly assigned to seven groups (comprising between 6 and 9 subjects) attending separately to participate in the tests at different times during a single day (and not meeting with other groups). Two groups were exposed to each of three alarms types in a randomised order, consisting of a sounder, long and short voice messages, the seventh (reserve group) was exposed to the short voice message. Tables 1 and 2 show the gender and age distributions of the subjects.

	Male	Female	Total
Sounder	6	11	17
Long message	4	12	16
Short message	5 (9)[1]	11 (17)[1]	16 (26)[1]

[1]Includes extra group (Group 6).

Table 1. Gender distribution.

	Under 21	21–30	31–40	41–50
Sounder	4	10	1	2
Long message	4	8	3	0
Short message	9 (15)	7 (11)	0	0
Total	17 (23)	25 (29)	0	0

Table 2. Age distribution.

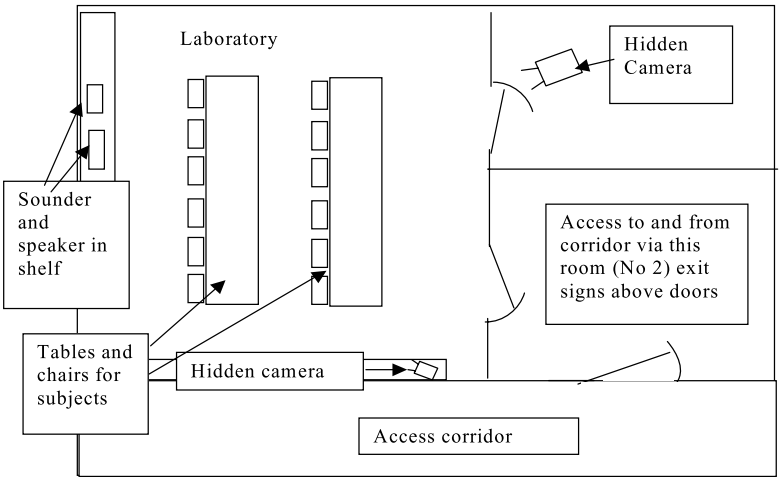

Fig. 1. Layout for alarms response experiments.

The layout of the psychology laboratory is shown in Fig. 1. The main camera was hidden in a darkened (closed) room, with a small subsidiary camera hidden on shelf in the laboratory. Each group of subjects gathered in Room 2, then moved into the laboratory, where the purpose of three (distracter) creativity tests was explained. Papers were then handed out and participants proceeded with the creativity tests. Subjects were asked to keep working through the tests. The experimenter announced that he would return when they had finished and then withdrew into the room containing the main camera. Approximately five minutes into the trials each group was subjected to an alarm. The subsequent behaviours were captured on video. The PTAT recognition and response times, and travel times to the room exit (marked with an exit sign) were recorded. Evacuating subjects were intercepted in the corridor. The

purpose of the experiment was explained and they were requested to fill in a short questionnaire about their experiences.

The three alarms used were as follows:

1. Alarm sounder
2. Long recorded female voice message: "Attention please! Attention please! This is an emergency. Please leave the building by your nearest exit" (total duration 9 seconds)
3. Short recorded female voice message: "This is an emergency! Please leave the building" (total duration 4 seconds)

All alarms were repeated continuously. The questionnaire was used to establish gender, age, previous experience with real life-threatening fire or bomb emergencies and number of fire drills previously involved in. Also, what the subject thought the alarm was for (choice from: fire, bomb, unknown, did not consider what it might be for, other). Further questions scored on a scale of 1–7: how seriously they took the alarm, to what extent they felt they should evacuate the room after hearing the alarm, to what extent they felt they were involved in a real emergency, the extent to which they were motivated by others and by the alarm, the extent to which they attempted to finish their activity before evacuating, their understanding of the voice message and a description of their thoughts and behaviour during the experiment. The "distracter" tasks consisted of a "vividness of visual imagery" questionnaire—rating intensity of mental images, a test making 16 pictures from triangles and twenty interpretations of inkblots.

All statistics were conducted using SPSS and Microsoft Excel. PTAT times could not be obtained from trial 6 (short message) because all occupants remained in the room throughout the test. Trial 6 may therefore have been invalidated so analyses have been carried out with and without trial 6 (which was repeated successfully by trial 7).

3 Results

3.1 Shopping Center Restaurant Evacuation

The results for the shopping centre restaurant evacuation are summarised in Fig. 2. Restaurant customers tended to listen to the alarm signal and the full spoken message while seated at their tables. This resulted in a recognition phase of 28–60 seconds, constituting the longest part of the evacuation time. Only one person started response behaviour before the end of the voice message. The response phase was relatively short, as was the travel phase. One customer waited until the repeat of the voice message before entering their response phase. Once occupants left the restaurant a further 30 seconds of so was required to exit the shopping mall. The staff left soon after the last customer.

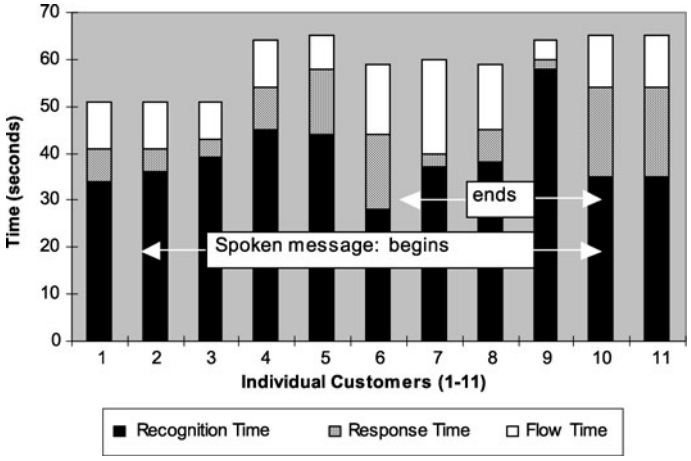

Fig. 2. Evacuation times for each customer leaving a restaurant.

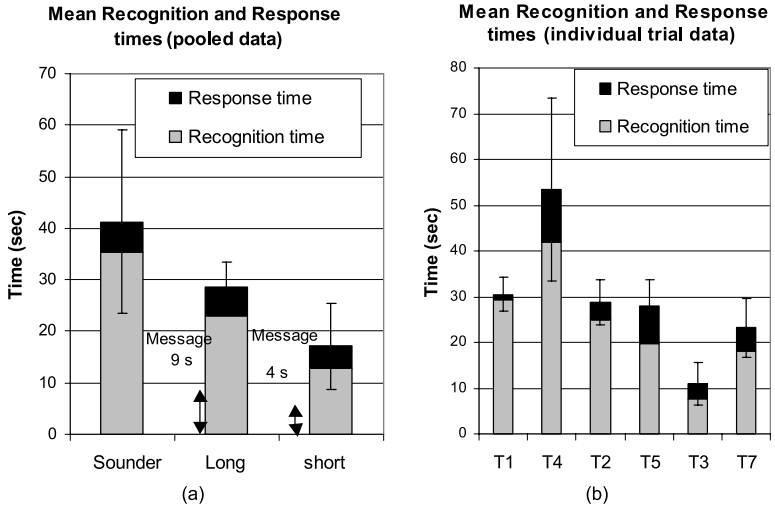

Fig. 3. Mean recognition and response times for Sounder (Trials 1 and 4), Long voice alarm (Trials 2 and 5) and Short voice alarm (Trials 3 and 7) bars show standard deviations.

3.2 Multistory Office Building Meeting Room Evacuation

The behaviour pattern in the office meeting room (Fig. 3) was similar (Table 3) to that in the restaurant. The mean recognition time (17 seconds) was the same as the time taken to deliver the message. All occupants then entered their response phase, getting up and collecting papers and or coats, before travelling to the room exit (one person re-entering to collect a jacket). For this case the response phase was slightly longer than the recognition phase,

Person	Recognition time (s)	Response time (s)	Travel to exit time (s)	Total time (s)
1	16	40	5	61
2	15	17	5	37
3	17	20	2	39
4	20	30	3	53
5	16	30	6	52
6	18	39	5	62
7	?	?	3	67
8	16	30	13	59*
9	?	?	?	55
10	?	?	?	65
11	?	?	2	71
12	?	?	4	51
Mean	17	29	5	56

(Sounder: 4 sec, Message: 13 sec, Total: 17 sec)
Movement to exit: Turned to face exit and leave room.
?—Location out of site of camera, location of occupant guessed.
*Re-enters to collect jacket. Leaves again at 00:01:24

Table 3. Response times of committee meeting room occupants.

and the mean PTAT at 46 seconds was longer than the average travel time of 5 seconds to the room exit (plus 5 seconds to the protected stair).

3.3 University Teaching Laboratory Experiment with Three Alarm Types

From the results of the monitored evacuations, it was considered that the voice alarms were effective, but that the travel phase of evacuation was delayed somewhat as occupants listened to rather long voice messages, in some cases waiting for the message to be repeated before starting to travel.

For this reason the short (4 second) message was included with the sounder and longer (9 second) voice message, which was the same as that used for the office building apart from the reference to the lifts. Also, for the experiments the voice messages were not preceded by a sounder alerting signal. Table 4 shows the individual data for the three alarms, and Table 5 the descriptive statistics. Figures 3, 4 and 5 illustrate key findings. The differences between the six groups for which data were obtain was highly significant (ANOVA $F2,47 = 18.66$, $P < 0.001$) and at the 5% level between pairs of alarm types. The results therefore confirmed that the voice messages provided significantly shorter pre-movement recognition times than did the sounder, and that the short message provided significantly shorter PTAT times than did the long message (except on the occasion when no response was obtained to the short message). Observations of the subjects indicated that a level of conformity

Sounder			Long voice message			Short voice message		
Recog.[1]	Rpnse[2]	PTAT	Recog.	Rpnse	PTAT	Recog.	Rpnse	PTAT
T1 26	0	26	T2 25	0	25	T3 10	6	16
32	0	32	25	0	25	8	0	8
32	0	32	27	0	27	7	0	7
27	0	27	18	8	26	8	5	13
29	0	29	22	0	22	8	9	17
30	1	31	25	9	34	8	5	13
27	0	27	26	7	33	8	0	8
33	1	34	26	10	36	5	0	5
29	8	37	31	0	31	T7 13	4	17
T2 18	5	23	T5 17	0	17	21	4	25
58	14	72	19	9	28	5	7	12
16	19	35	19	11	30	13	10	23
16	24	40	19	9	28	20	3	23
63	5	68	22	10	32	25	0	25
60	14	74	22	11	33	26	7	33
60	10	70				22	6	28
45	0	45						

[1]Recognition time [2]Response time

Table 4. Individual recognition, response and PTAT for three alarms.

Alarm type/trial	n	Recognition time (s)				Response time (s)			
		Mean	s.d.	Min	Max	Mean	s.d.	Min	Max
Sounder									
Trial 1	9	29.4	2.51	26	33	1.1	2.62	0	8
Trial 4	8	42	21.69	16	63	11.4	7.96	0	24
Pooled	**17**	**35.4**	**15.81**	**16**	**63**	**5.9**	**7.68**	**0**	**24**
Long message									
Trial 2	9	25	3.54	18	31	3.8	4.55	0	10
Trial 5	6	19.7	1.97	17	22	8.3	4.18	0	11
Pooled	**15**	**22.9**	**3.98**	**17**	**31**	**5.6**	**4.84**	**0**	**11**
Short message									
Trial 3	8	7.8	1.39	5	10	3.1	3.56	0	6
Trial 7	8	18.1	7.18	5	26	5.1	3.04	0	10
Pooled	**16**	**12.9**	**7.33**	**5**	**26**	**4.22**	**3.25**	**0**	**10**

Table 5. Mean PTAT recognition and response times for three alarm types.

and/or group reference was involved in the decision to evacuate and its timing. Subjects looked around and consulted each other before leaving the room. There were often a few key individuals who initiated (or inhibited) the whole group decision to evacuate. The majority of subjects were students but a few older staff members participated. It was notable that on one occasion a female staff subject took a leading role and initiated a timely evacuation. On another

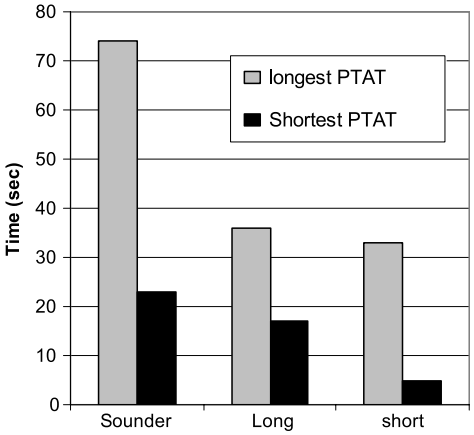

Fig. 4. Shortest and longest PTAT.

occasion a young male suggested that the alarm was not genuine and refused to leave but was left by the group. In trial 6 a few individuals picked up bags as if to leave but put them down when a male subject convinced them the alarm was part of the test, and that they should not respond. It is considered that such group dynamics can be very important in real emergencies and that the results obtained here are somewhat similar to those where subjects fail to respond because they believe an alarm to be a drill.

The basic finding was that the short voice alarm provided the shortest recognition and total PTAT times (Figs. 3 and 4), the long voice message somewhat longer times, and the sounder the longest times. Travel times from this small laboratory were similar to those from the office meeting room at around 5 seconds. As Fig. 3 shows, the sounder produced the most variable PTAT times, with considerable differences between the two trials. The long voice message produced the most reliable and least variable PTAT times, with very similar results for the two trials. The short message produced a more variable response than the long message, with some differences between the two successful trials, and a less reliable response due to the failure of Trial 6. Figure 4 shows the variability in terms of the shortest and longest PTATs for each case.

As with the monitored evacuations, the recognition phase was the longest part of the PTAT response. Once subjects decided to leave the room, they generally stood up, and either started to travel immediately (response time 0 seconds) or collected any belongings and started to travel (within 10 seconds response time for the voice alarms, but longer [within 25 seconds] for the sounder). Occupants tended to listen to the full message and its first repeat before beginning the response and travel phases of their evacuation. Figure 5 shows the PTAT distributions for each trial. The results for each pair of trials are summed to illustrate the distribution of times.

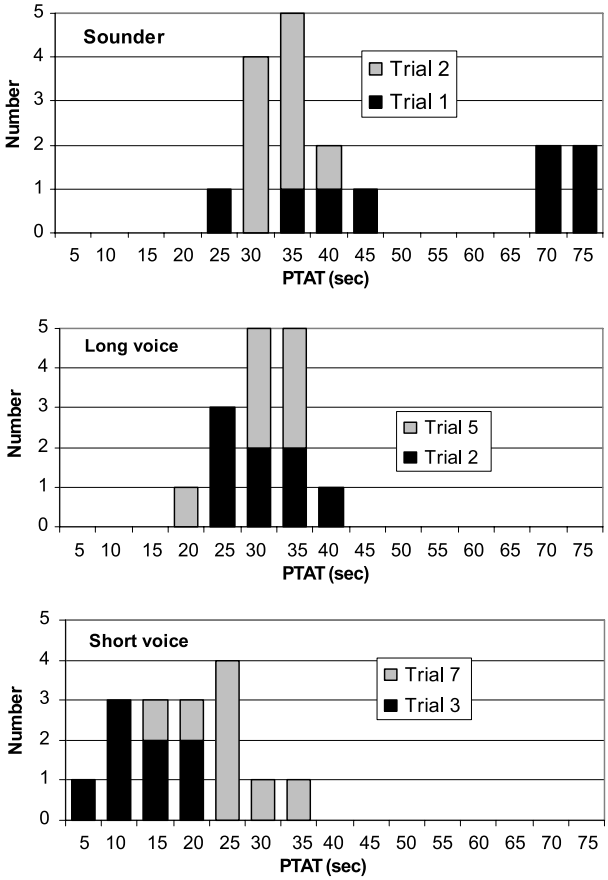

Fig. 5. PTAT distributions.

3.4 Findings from Questionnaire—University Teaching Laboratory Experiment with Three Alarm Types

The response to a multiple choice question about the perceived purpose of the alarm indicated that the majority of subjects interpreted each alarm type as a genuine fire/emergency warning (Table 6), with the exception of the short voice message, which was more likely to be perceived as part of the experiment. This was still the case even when trial 6 was excluded. In all cases where "other" was selected subjects expressed doubt as to the authenticity of the alarm and thought it might be part of the experiment. Subjects were significantly more motivated to leave the room by the long message than by the short message.

Response to the question "To what extent did you attempt to finish the activity you were involved in before leaving the room?" showed some indica-

Answer choice	Sounder	Long message	Short message	Total
Fire/emergency warning	8	6	3	17
Bomb warning	0	3	0	3
Could be either of the above	1	1	3 *(4)*	5 *(6)*
Did not know	1	0	1	2
Did not consider purpose	1	2	2 *(3)*	5 *(6)*
Other	6	4	7 *(15)*	7 *(25)*
Total	17	16	16 *(26)*	49 *(59)*

*(Italics: including trial 6)

Table 6. Perceived purpose of alarm from multiple choice question.

	Mean	s.d.	Cases
Sounder	2.53	1.50	17
Long voice	2.00	1.37	16
Short voice	2.13 (3.54)	1.45 (2.45)	16 *(26)*

*(Italics: including trial 6). s.d. = standard deviation

Table 7. Descriptive statistics for commitment to task and alarm type.

tion of differences between alarm types, which was significant if Trial 6 was included in the analysis ($P < 0.04$) (see Table 7).

There was no significant interaction between alarm types and previous experience with fires or bombs and reaction times, or with perceived seriousness of alarm and reaction times. Of the subjects, 20% had previous experience of a fire incident, 34% a bomb threat incident, and all had previous experience of a number of emergency evacuation drills.

4 Discussion

4.1 Effects of Alarm Type on PTAT Recognition and Response Times

The overall findings of the experimental study were that voice messages produced shorter and more reliable PTAT times than a sounder, which is in agreement with the two previous 1990/1 studies in the London office and underground Metro [4, 5] and other studies [1, 6]. The short message used in the experiment produced the shortest times, but the response was less reliable. The PTAT times for the voice alarms were also similar to those obtained in the earlier studies with mean values of 28 and 17 seconds (maximum 36 and 33 seconds) compared with previously reported maximum values of 30 and 75 seconds [4, 5]. These are also similar to the PTAT times obtained during the monitored office evacuation (maximum 60 seconds) and the shopping centre restaurant (maximum 103 seconds). However the PTAT times obtained using the sounder in the experimental study, although longer than those for the

voice alarms, were also short (mean 41, maximum 74 seconds) with effective evacuations, compared to the 11 and 9 minutes values reported in the earlier studies.

The analysis of both the monitored evacuations and the experimental study showed that the longest component of the evacuation time for both sounder and voice alarms systems was the recognition time. During the period subjects continued with the activities they were engaged in before the alarm sounded, or paused the activities to consider the implications of the alarm. In all three situations reported occupants were all seated at the time the alarm occurred, and all remained seated during the recognition phase. During this period for the sounder (in the experimental study) subjects appeared to be spending some time considering what action to take and tended to look at or consult each other before coming to a decision on a course of action. For the voice alarms they listened to the full voice message (sometimes plus a repeat) before taking action. In this context the use of a shorter voice message definitely reduced the time required to come to a response decision. There were indications that the long voice message was more effective in reducing commitment to the pre-alarm activity.

The office building meeting room and the university experiment both represented relatively simple situations with respect to response period behaviours. The subjects were in small rooms, present as individuals with relatively few commitments or belongings. The response period activities therefore required a relatively short time to complete compared with much more complex behavioural scenarios involved in some fire incidents [1, 7, 8]. The rapid recognition and short response times in the restaurant are of interest, since it has been suggested in actual incidents that occupants can be reluctant to cease eating and leave food (show high commitment) [8].

The questionnaire showed no significant interactions between alarm type, PTAT times and effects of previous experience with fires or fire drills, or bombs. Although it is possible factors such as these may have influenced overall responsiveness to all alarms, the mean scores on these aspects were relatively neutral (i.e. ∼3–4.5 out of 7).

4.2 Perceived Seriousness of the Alarm

An issue with respect to university evacuation experiments was the extent to which subjects look the alarms seriously, since the alarms were not integrated into the building systems. The response to the multiple choice question indicated that the majority of subjects interpreted each alarm type as a genuine fire/emergency warning, with the exception of the short voice message, which was more likely to be perceived as part of the experiment. Some subjects expressed doubt as to the authenticity of the alarm and thought it might be part of the experiment, particularly for the failed short voice message (Trial 6). It is considered that in this regard the experiment findings were similar to those in monitored evacuations and genuine emergencies, in which occupants “often

treat real alarms as false alarms because they cannot see, smell or hear the fire, which may be on another floor" (J. Scanlon [9]).

4.3 Group Interactions

It was evident from observation of the video records that interactions between group members had a strong influence on evacuation behaviour and evacuation times. Subjects looked around and consulted each other before leaving the room, and as described, there were often a few key individuals who initiated (or inhibited) the whole group decision to evacuate (with an older person expediting the group response on one occasion, and younger members either unsuccessfully or successfully preventing evacuation. It is considered that such group dynamics can be very important in real emergencies. The results obtained here with Tral 6 are somewhat similar to those where subjects believe an alarm to be a drill and fail to respond, convincing each other that this is the case. Although differences between alarm types were not significant with respect to "motivation by others to leave the room", the relatively high mean scores (scale 1–7) for this (sounder 5.0, Long voice 3.9 and short voice 4.8), suggest this may have been a factor, especially for the sounder case.

4.4 Design Behavioural Scenarios

The response of subjects to fire alarms is considered to be influenced by a number of parameters related to their individual characteristics and the building environment, but from previous studies it is considered that PTAT times and distributions are highly dependent upon a small number of key characteristics, which can be classified into a small number of design behavioural scenarios for the collection of data sets and for application to design cases [2, 3, 10]. The scenarios presented here could be classified as "awake and unfamiliar", in that in all cases the occupants can be considered as largely unfamiliar with the buildings and alarm systems. In such situations voice alarm systems have been found to be particularly appropriate and effective. A further important consideration is the influence of evacuation management by trained staff. It is considered that the restaurant staff encouraged efficient evacuation for the restaurant case and that the scenario was well-managed. For the office meeting room case the building was well-managed and it is believed that a least one of the occupants was familiar with the building systems. The university experiment would not normally be considered to represent a well-managed case, but it is considered that since many of the participants had previous experience of fire drills or other emergency evacuations they behaved as well-trained individuals.

5 Conclusion

Voice alarms are more effective than sounders, providing shorter and more reliable evacuation pre-travel activity response times (PTAT), especially in "Awake and unfamiliar" Design Behavioural Scenarios.

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