Localizable sound and its application in guiding passengers towards exits during aircraft evacuations

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Abstract

Transport Canada has funded cabin safety research programmes within the Human Factors Group at Cranfield University for a number of years. One recent programme, carried out in collaboration with the ISVR at the University of Southampton, was concerned with passengers' ability to localise sound within an aircraft cabin. Sounds that can be easily localised may help to guide passengers to exits during aircraft evacuations when visibility is poor.

A comprehensive literature review was undertaken to study previous applications of sounds in way-finding and evacuation, to explore what qualities or characteristics would make sounds most effective, and to explore operational constraints that may apply particularly in aircraft. For example, opportunities to familiarise airline passengers with the meaning and use of evacuation sounds may be limited, whereas in the workplace, employees would become familiar with the sounds and procedures through recurrent training and emergency drills.

Based on the literature review, several candidate sounds were designed and tested. Candidate sounds were designed to have characteristics associated with highly localizable sound, and were tested in an anechoic chamber to assess the extent to which participants could localize each of the sounds. 'White noise' or broadband sound is generally accepted to be among the best, if not the best localised of sounds. The results of the experiment showed that a carefully designed sound, a multi-component complex tone developed specifically for the research, was localized almost as well as broadband sound.

The optimum complex tone had a distinctive timbre and pitch, making it recognisable as an evacuation or warning signal, unlike white noise. Complex tones may also be easier to detect than white noise above background noise. Consequently, well localized complex tones such as this may be even more effective than broadband sound for assisting passenger evacuations.

1. Introduction

1.1. Background

Localizable or directional sound has been used in a number of settings to provide spatial information to people. One of the main applications is in the provision of way-guidance or evacuation information. In essence, localizable sounds from sound beacons are used to guide people from point to point along an escape or route, or to mark the locations of exits and doorways. Such systems have been used in various environments, including mines, road tunnels, and aircraft. Potential advantages include the language free nature of the signal, and the ability to provide information with minimal reliance on sight. This is useful in conditions of smoke and/or poor visibility, and is not solely a benefit for the visually impaired. A well designed sound can also convey additional meaning, such as urgency, which could improve speed of evacuations and result in fewer injuries or fatalities. However, many of these potential advantages will only be realised if the sound signal and sound equipment are appropriate for the intended use: in aircraft the sounds and the system must take account of the cabin acoustics and cabin layout, seating and aisle plans, the location and number of exits, and which exits are viable.

1.2. Localizable sound in mines

In 1994, many mines throughout South Africa were equipped with 'MOSES', the Mainsfail Operated Evacuation System (Gouws and Phillips 1995). This was developed to guide miners through the mine to safety or refuge points under low visibility conditions such as those that would be experienced after an explosion. This system used sound beacons attached to the mine face at 50 metre intervals. The beacons would emit synchronised sound to guide miners in the direction of safety, and the sound would only disappear at refuge points, denoting that a safe haven had been reached. MOSES was considered to be an active system of way finding under low visibility conditions. Previous, passive systems involved miners using tactile guiding systems incorporating rails, ropes and cables. One of the major disadvantages of passive systems was that they were often partially destroyed during explosions. The first version of MOSES also suffered from this problem, as beacons were connected and powered using a network of cables. However, MOSES II included a battery pack lasting several hours. The improved system ensured that the sound emitted would be synchronised, and that there would not be a break in the signal for more than two seconds. Gouws and Phillips (1995) suggested that the only potential disadvantage to MOSES II was loss of hearing due to an explosion, and that the primary benefit was the directional component.

1.3. Localizable sound in road tunnels

One recent study (Boer, 2002) investigated broadband sound beacons in a road tunnel. The aim of was to compare motorists' behaviour with and without the use of directional sound. The sound was intended to instigate the evacuation procedures, and to direct participants through the smoke filled environment to safety. Beacons were placed above emergency exit doors, and participants were brought into the tunnel by bus. They were asked to leave their vehicles and escape through dense smoke on foot. There were three conditions for these evacuation demonstrations. In the first condition, participants were not given any information regarding the sound beacons at all. In the second condition, participants were informed that there were sound beacons by which they could orientate themselves and that they should listen to them. The third condition informed participants that there were sound beacons by which they could orientate themselves, and they were told that the sound beacons were placed above emergency exit doors, that they should listen to the sound, and go to an emergency exit.

The first condition resulted in the slowest evacuation times. Thermal imaging cameras showed participants making their way out of the tunnel in the direction by which they entered. Most participants did so by feeling their way using the tunnel wall. The third condition resulted in the fastest evacuation times, although some motorists missed the emergency exit doors because of the poor visibility. Interestingly, those participants who had been given full instructions about how to use directional sound to evacuate did not walk significantly faster than those who had no instruction. Instead, fully informed participants seemed to find the nearest emergency exit, whereas participants who had no instruction attempted to evacuate the tunnel from the direction in which they had entered. Those who went in the opposite direction often walked past an emergency exit.

Motorists were found to be more confident in their response when they knew that the sound beacon meant “evacuate immediately”, and when they were made aware of the sound’s purpose. Boer (2002) recommended that vocal instruction be given, telling motorists to leave their cars and evacuate the tunnel following the sound. However, one of the advantages of localizable sound itself is that it is not language dependent, although a briefing on interpreting the sound may well be. The participants’ comments on the directional sound signal were revealing. One participant stated that they thought the signal meant they should move past the exits, contrary to the intended meaning. Six percent of participants from the second condition, in which participants were told to orientate themselves using the signal, and fifteen percent from the third condition, where participants were told to listen to the beacons placed over the exits and to move towards them, reported issues with the sound signal itself. Comments included statements that the broadband noise was a ‘a strange sound’, ‘hissing’, ‘steam’, like ‘machines’, ‘didn’t sound like a beacon’, ‘unsafe’, ‘don’t think it’s good’ (Boer 2002, pg54).

1.4. Localizable sound in civil aviation

Lower, Patterson, Patten and Milroy (1992) reported on sounds developed for a UK Civil Aviation Authority research programme, conducted to investigate the potential benefits of audio attraction with sounders at the aircraft exits. Tests were carried out in a Trident cabin. The sounds were bursts of multi-frequency pulses, the onset and offset of which were rounded to reduce any possible startling effect. The sequences of pulses also presented a distinctive rhythm which has been shown to be less confusing in auditory warning signals (e.g. Patterson, 1982). The pulses themselves, and the time in between pulses, were shortened in order to generate a perception of urgency in the warning signal. A large number of frequency components or harmonics were also used to ensure that the sound was not masked by any sudden noise in the cabin. The sound level of the signal fell off with distance by about 15 dB along the full length of the cabin. In artificial smoke, the sound level was reduced by a further 10 dB at the seats most distant from the loudspeaker, giving a total reduction of 25 dB along the cabin length. Despite this, when asked to identify which loudspeaker the signal came from, participants were able to correctly identify and localise the signal on more than 95% of occasions. Thus, the audio warning signal was considered to be effective in terms of audio attraction.

Muir and Bottomley (1992) used this signal in evacuation trials. Loudspeakers were placed above both Type I (bulkhead) and Type III (over-wing) exits of a Trident airframe. Experimental groups of 30 participants were involved in evacuation trials through Type I and Type III with the sound, control groups evacuated without the sound. There were small improvements in evacuation times for the trials using sound, but the differences were not statistically significant. This may have been because it was not possible to locate a loudspeaker immediately above the Type I exit, because of the Trident's up-and-over door mechanism and counterweight. The audio attraction loudspeaker was therefore in a less satisfactory position, in the bulkhead separating the cabin from the exit. Passengers had to pass the loudspeaker to reach the exit, and once they had reached the loudspeaker they had to move away from the loudspeaker rather than towards it. Hence, in certain evacuations, the loudspeaker then became counter productive, especially when the sound was encountered for the first time. This research showed that the location of the loudspeakers was critically important in ensuring that the perceived sound location was consistent with the exit location.

More recently, broadband sound was used in aircraft evacuations to provide directional information (Withington, 2001). In this instance, the sound beacons were fitted above the exit locations. The "passengers" were volunteers, randomly allocated to seats within the cabin. Once seated, the cabin was filled with non-toxic smoke, and after approximately five minutes, the volunteers were required to evacuate. Three exits were made available, and the results appeared to indicate that the sound had been helpful in optimising the distribution of volunteers through the available exits. However, the demonstrations were not controlled experimentally, and it is difficult to draw any firm conclusions from the work. In addition, perhaps because of commercial sensitivity, no detailed statistical analyses were reported. It is therefore difficult to quantify the effect of the sound beacons from the published data.

1.4. Localizable sound and certification issues

Broadband sound has certain characteristics which are known to be conducive to localization, and hence it is used in proprietary systems such as the one developed and marketed by Sound Alert (Withington, 1999). However, there is little information in the public domain relating to the use of localizable sounds in aviation, perhaps because of commercial sensitivities. Nevertheless, regulatory authorities will need to have a clear understanding of the factors influencing passengers' ability to localize sound, as well as a standard protocol for testing proposed systems. This will be necessary to ensure that different systems operate with a reasonable degree of equivalence and standardisation of sounds, and to provide operators with guidance on how to fit such a system to ensure optimal localization in any given cabin configuration. Ideally, regulators should be able to offer an 'open-source' alternative to proprietary systems or sounds.

As an initial step in addressing these issues, Transport Canada commissioned an independent research programme to investigate the use of directional sound to guide passengers to the exits of aircraft during emergency evacuations. The study was undertaken by ISVR Consulting, the consultancy unit of the Institute of Sound and Vibration Research at the University of Southampton, and the Human Factors Group in the School of Engineering at Cranfield University. The first stage of the study involved a review of the research literature on sound localization, and on the use of sound as a guidance system during emergencies (Kay, Lower & Thomas, 2004). The objective was to learn from the experience of others a) what types of sound are most easily located by listeners, b) what characteristics of a sound make it easily located, c) how sound has been applied in different environments, and d) what factors have contributed to the success or failure of particular sounds in evacuating people from hazardous surrounds. The second stage of the study involved designing sounds that were likely to be easily identified and localized. These sounds were then evaluated through experimental testing to determine which of the sounds was the most effectively localized. Future work will involve testing sounds in an aircraft cabin simulator.

2. Method

2.1. Sound design

A selection of sounds was generated for the experimental trials. The objective was to select one or more highly localizable and distinctive sounds suitable for use in a sound beacon. As well as building on the results of previous research in this area, the design of the sounds was guided by the experience of ISVR in similar projects, for both civil and military application. It was clear from the literature search that one of the sounds should be broadband noise. A broadband noise signal, such as 'white noise' or 'pink noise' is usually the best for listeners to localize. The interstation hiss on FM radios is a familiar example of broadband noise. However, broadband noise alone is not particularly distinctive, it may not be attention grabbing unless it is loud, and is not immediately identifiable as a warning sound to naïve listeners.

Most of the other sounds developed for the experimental work were complex tones. Complex tones are signals made up of many separate pure tone components. The pitch and timbre (sound quality) can be controlled by careful choice of the frequency components, which allows distinctive sounds to be generated. Pure tone signals, that is, those with a single frequency, were included for comparison. However, it was expected that these tones would be poorly localized compared to broadband sound and complex tones. The complex tones and pure tones were generated digitally using Matlab software. The broadband signal (white noise) was generated digitally using 'Adobe Audition' program.

Approximately 40 different complex tone signals were generated initially. The earliest produced had a bandwidth extending to 8 kHz, but later examples had components up to 10 kHz. The complex tone signals fell into distinct sets. Some signals had equally spaced frequency components, e.g. components every 100 Hz or every 200 Hz. These signals were generally clearly identifiable as electronically generated buzzes, typical of many warning sounds, but they had the advantage that a high density of components could be achieved across the whole frequency range. From previous experience at ISVR, this has been known to improve localization properties.

Some signals were series of components in which each component except the first was a given multiple of the previous, e.g. 100 Hz, 200 Hz, 400 Hz, 800 Hz, etc. These had a musical quality similar to organ notes, but generally fewer components could be fitted into a given frequency range. Other signals were combinations of two series of components, e.g. a harmonic series of equally spaced components such as 200 Hz, 400 Hz, 600 Hz, etc with a second series superimposed, such as 230 Hz, 430 Hz, 630 Hz, etc. The components of the second series were displaced from those of the first series by a fixed amount, by 30 Hz in this example. Such signals had a distinctive, rough, discordant, beating quality, while retaining a definite pitch. The beating caused modulation in the signal amplitude, which could assist localization.

The forty or so sounds were quickly reduced to a shortlist of ten. The broadband noise signal was included as this was likely to be the most easily located. A high-frequency and a low-frequency tone were included, as these were likely to be poorly located. The remaining seven sounds for the experimental tests were chosen from the complex tone signals. The sounds chosen were those with distinctive sounds, those with a large number of frequency components, and those with a degree of amplitude modulation obtained by beating of two sets of frequencies. A sound with a large number of frequency components or modulation in amplitude is more likely to be easily localized. Sounds were eliminated if they were similar to sounds already chosen, with only minor differences in pitch, for example. The shortlisted sounds, numbered from Sound 1 to Sound 10, are described in Table 1.

Table 1: Shortlisted sounds for evaluation in the anechoic room

Sound	Description
1	Tone: Single component at 2500 Hz
2	Tone: Single component at 440 Hz
3	Complex tone: 25 components at 400 Hz intervals from 425 Hz to 10025 Hz; i.e. 425 Hz, 825 Hz, 1225 Hz, to 9625 Hz, 10025 Hz
4	Complex tone: 33 components at 300 Hz intervals from 300 Hz to 9 900 Hz; i.e. 300 Hz, 600 Hz, 900 Hz, to 9600 Hz, 9900 Hz
5	Complex tone: 7 components spaced an octave apart with 100 Hz fundamental frequency, i.e. 100 Hz, 200 Hz, 400 Hz, 800 Hz, 1600 Hz, 3200 Hz, 6400 Hz
6	Complex tone: 6 components spaced one octave apart with 300 Hz fundamental frequency, i.e. 300 Hz, 600 Hz, 1200 Hz, 2400 Hz, 4800 Hz, 9600 Hz
7	Complex tone: 12 components of which 6 components are an octave apart with a 200 Hz fundamental frequency, then additional components at 30 Hz above each of the original 6 i.e. 200 Hz, *230 Hz*, 400 Hz, *430 Hz*, 800 Hz, *830 Hz*, 1600 Hz, *1630 Hz*, 3200 Hz, *3230 Hz*, 6400 Hz, *6430 Hz*
8	Complex tone: 80 components comprising 40 components at 200 Hz intervals from 200 Hz to 8 000 Hz, with additional components at 30 Hz above the original 40 i.e. 200 Hz, *230 Hz*, 400 Hz, *430 Hz*, 600 Hz, *630 Hz*, 800 Hz, *830 Hz*, to 7800 Hz, *7830 Hz*, 8000 Hz, *8030 Hz*
9	Broadband, random (white) noise, extending to 11 kHz
10	Complex tone: 100 frequency components at 100 Hz spacing from 100 Hz to 10000 Hz

The ten shortlisted sounds were then tested to determine how well listeners could localize them. Volunteer participants were recruited to take part in sound localization trials within an anechoic room. They were seated at the centre of an arc of loudspeakers, and were required to identify from which loudspeaker a sound was presented each time. The experimental procedure was as detailed below. This experimental protocol was approved by the Institute of Sound and Vibration Research Safety and Ethics Committee at the University of Southampton.

2.2. Test facility

The tests were carried out in the smaller anechoic room in the ISVR's Rayleigh Laboratories at the University of Southampton. An anechoic room is a special test room in which the walls, floor and ceiling are lined with sound absorbent material to minimise reflections from the room boundaries. The sound field in the room is a free field, with no reverberation or echoes. The room is acoustically 'dead'.

2.3. Participants

Ten participants, six male and four female, took part in two sessions each. Participants were students from the University of Southampton. Their hearing was not formally tested, but none admitted to any hearing difficulties and none had recently suffered from a cold or other infection that might temporarily affect their ears or hearing. Participants were paid £20 for their participation.

2.4. Equipment

The equipment used for the trials is shown schematically in Figure 1. The ten shortlisted test sounds were stored as 'wav' files on the hard disk of a personal computer. The sounds were replayed from the computer through an external sound card to a power amplifier, then through a loudspeaker selection switch to one of eleven loudspeakers in the anechoic room. The eleven loudspeakers were located with their centres 1.2 metres above the floor, in a horizontal arc 3 metres in diameter spanning 180^{o}. The loudspeakers were facing inwards towards the focus of the arc. A chair was positioned so that the centre of the head of a seated participant was at the focus, with the loudspeakers at ear height. The loudspeaker selection switch was controlled by the personal computer that generated the test sounds. The computer selected the loudspeaker before each presentation of a test sound.

2.5. Sounds

The test sounds had originally been produced as 'wav' files, each with a duration of one second. This duration was considered too long for these tests: participants would have time to move their heads and home in on the sound source, giving near perfect localization and not revealing any differences between sounds. Therefore, for these tests the test sounds were shortened and pulsed. The shortening and pulsing was achieved by loading each sound into 'Adobe Audition' software, applying an envelope to the waveform, and then resaving the sound as a new 'wav' file. The new sounds were each made up of two pulses, 100 ms long, separated by 50 ms. The rise and fall times of the pulses were approximately 5 ms. The pulse duration used in these tests is not necessarily the optimum for use during aircraft evacuations: longer or shorter pulses may eventually be used.

Before the tests, the sound level of each of the test signals was measured using a sound level meter at the position to be occupied by the participant's head. The sound levels were adjusted, using a volume control within the computer software, so that each of the test sounds produced the same sound level (65 dB(A) nominally).

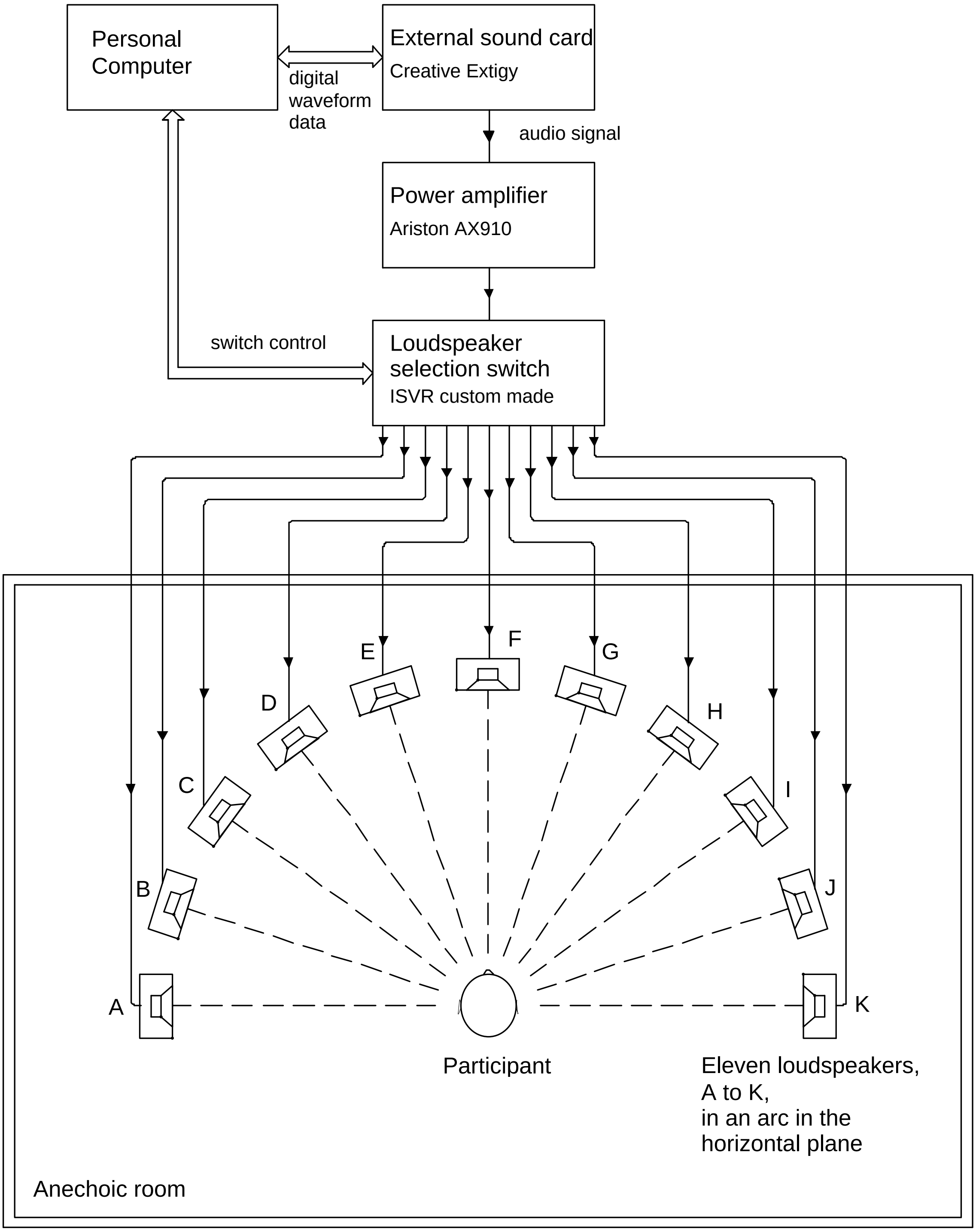

Figure 1: Schematic representation of the anechoic room set-up

2.6. Experimental design

The number of participants and the number of sounds were chosen to be the same so that a fully counterbalanced design could be used. Each participant attended two sessions on different days. In this design, the order of presentation of the sounds was varied from participant to participant and from session to session, so that one participant would hear Sound 1 first, another would hear Sound 2 first, etc. Over the complete experiment, with two sessions per participant, each sound occurred first in the order of presentation the same number of times, each sound occurred second the same number of times, etc. and each sound preceded and followed each of the other sounds the same number of times. In this way, any learning or practice effects which might improve a listener's performance, or any loss of attention towards the end of a test, were spread equally amongst the sounds, and any bias favouring one sound over another was removed.

2.7. Test procedure

Each participant was greeted on arriving for his or her first session. The purpose of the tests and the nature of the participant's task were explained, and the researcher and participant completed a consent form to confirm this. The participant was shown into the anechoic room and seated in position. The loudspeakers and their labelling were pointed out, and any questions about the procedure were answered. The researcher then left the anechoic room and the tests commenced.

The researcher consulted the experimental design, entered the number of the first test sound into the computer, and set the appropriate volume. The researcher then started the test sequence. The computer selected a loudspeaker at random, set the loudspeaker selection switch and replayed the sound through the appropriate loudspeaker. The participant then reported, using an intercom to the researcher, which of the loudspeakers, from A to K, the sound had apparently originated from. The researcher entered the participant's response into the computer, which stored the results for analysis. The computer then selected a loudspeaker at random and the test continued until the test sound had been played 33 times, i.e. 3 times through each loudspeaker. The researcher then entered the number of the second test sound, according to the experimental design, and the test was repeated with the new sound, which was also replayed 33 times. The testing continued until all ten sounds had been tested.

As the computer selected the order of the loudspeakers, it was possible for a test sound to be presented from the same loudspeaker twice in succession, and this did occur occasionally. To prevent the participant using the loudness of a sound as a cue to its direction, the computer was programmed to vary the level of the digital signal that was output to the sound card. Although each sound was presented three times through each loudspeaker during a session, its sound level would be slightly different on each presentation. One presentation would be at the nominal sound level of 65 dB(A), one would be 5 dB higher and one would be 5 dB lower than nominal. Thus during the set of thirty-three presentations of each sound during a session, the sound would vary in both level and the direction.

The second session for each participant was the same as the first, except that the preliminary detailed instructions and the signing of a consent form were not necessary, the sounds were tested in a different order, and the participant was thanked for attending and was paid on completion. Each session lasted approximately 25 to 30 minutes.

3. Results

During the tests, each time a participant reported which loudspeaker a sound had come from, the participant was either correct or incorrect. The number of correct responses was counted for each sound, and the sound with the highest score or most correct responses was taken as the sound that was best localized. Tables 2a to 2c show the results of the tests analysed in this way. Table 2a shows the percentage of correct responses for each participant in the first test session only; Table 2b shows the percentage of correct responses for each participant in the second test session only; and Table 2c shows the percentage of correct responses by sound and participant combined over both test sessions.

Table 2a: Correct responses by sound and participant, first test session

Sound	**Percentage of correct responses (%)**										
	Participant Number										
	1	2	3	4	5	6	7	8	9	10	Mean
1	33.3	69.7	54.5	63.6	39.4	57.6	42.4	27.3	30.3	42.4	46.1
2	69.7	90.9	84.8	81.8	54.5	84.8	75.8	57.6	42.4	75.8	71.8
3	93.9	81.8	81.8	75.8	39.4	81.8	66.7	51.5	51.5	72.7	69.7
4	78.8	87.9	87.9	69.7	60.6	69.7	75.8	51.5	75.8	78.8	73.6
5	69.7	81.8	54.5	87.9	72.7	87.9	78.8	54.5	72.7	63.6	72.4
6	81.8	87.9	60.6	84.8	60.6	69.7	60.6	39.4	48.5	72.7	66.7
7	78.8	93.9	60.6	84.8	72.7	78.8	81.8	72.7	48.5	78.8	75.2
8	78.8	93.9	69.7	87.9	60.6	78.8	81.8	90.9	42.4	90.9	77.6
9	78.8	97.0	97.0	90.9	63.6	78.8	81.8	72.7	45.5	75.8	78.2
10	78.8	81.8	84.8	97.0	54.5	90.9	75.8	87.9	39.4	84.8	77.6
Mean	74.2	86.7	73.6	82.4	57.9	77.9	72.1	60.6	49.7	73.6	70.9

Table 2b: Correct responses by sound and participant, second test session

Sound	**Percentage of correct responses (%)**										
	Participant Number										
	1	2	3	4	5	6	7	8	9	10	Mean
1	36.4	57.6	30.3	54.5	45.5	42.4	63.6	30.3	36.4	27.3	42.4
2	72.7	81.8	51.5	84.8	48.5	97.0	75.8	72.7	54.5	60.6	70.0
3	75.8	84.8	78.8	78.8	48.5	87.9	75.8	84.8	51.5	63.6	73.0
4	78.8	66.7	93.9	63.6	36.4	84.8	81.8	78.8	63.6	78.8	72.7
5	69.7	87.9	75.8	69.7	42.4	81.8	90.9	87.9	48.5	63.6	71.8
6	75.8	81.8	90.9	72.7	54.5	87.9	72.7	78.8	51.5	63.6	73.0
7	66.7	87.9	90.9	84.8	42.4	81.8	93.9	90.9	66.7	54.5	76.1
8	87.9	93.9	90.9	78.8	57.6	87.9	93.9	93.9	78.8	75.8	83.9
9	81.8	100.0	97.0	72.7	66.7	84.8	90.9	87.9	84.8	75.8	84.2
10	93.9	78.8	84.8	69.7	45.5	90.9	81.8	66.7	66.7	69.7	74.8
Mean	73.9	82.1	78.5	73.0	48.8	82.7	82.1	77.3	60.3	63.3	72.2

Table 2c: Correct responses by sound and participant, both test sessions

Sound	**Percentage of correct responses (%)**										
	Participant Number										
	1	2	3	4	5	6	7	8	9	10	Mean
1	34.8	63.6	42.4	59.1	42.4	50.0	53.0	28.8	33.3	34.8	44.2
2	71.2	86.4	68.2	83.3	51.5	90.9	75.8	65.2	48.5	68.2	70.9
3	84.8	83.3	80.3	77.3	43.9	84.8	71.2	68.2	51.5	68.2	71.4
4	78.8	77.3	90.9	66.7	48.5	77.3	78.8	65.2	69.7	78.8	73.2
5	69.7	84.8	65.2	78.8	57.6	84.8	84.8	71.2	60.6	63.6	72.1
6	78.8	84.8	75.8	78.8	57.6	78.8	66.7	59.1	50.0	68.2	69.8
7	72.7	90.9	75.8	84.8	57.6	80.3	87.9	81.8	57.6	66.7	75.6
8	83.3	93.9	80.3	83.3	59.1	83.3	87.9	92.4	60.6	83.3	80.8
9	80.3	98.5	97.0	81.8	65.2	81.8	86.4	80.3	65.2	75.8	81.2
10	86.4	80.3	84.8	83.3	50.0	90.9	78.8	77.3	53.0	77.3	76.2
Mean	74.1	84.4	76.1	77.7	53.3	80.3	77.1	68.9	55.0	68.5	71.5

Table 3: Rank order of localizability of Sounds 1-10 using the correct response method

First session	**Second session**	**Overall (both sessions)**
9	9	9
10	8	8
8	7	10
7	10	7
4	3	4
5	6	5
2	4	3
3	5	2
6	2	6
1	1	1

Sound 9, Sound 8, Sound 10 and Sound 7 are consistently well localized, and Sound 9 is consistently the best when averaged over all the participants. Inspection of Table 2c, which gives results for individual participants, shows that participants varied in the sound which they localized the best. Sound 9 scored highest with four of the participants, Sound 8 scored highest or joint highest with 3 of the participants, Sound 10 scored highest with two of the participants, and Sound 7 scored highest or joint highest with 2 of the participants.

Thus although Sound 9 scored highest overall, with 81.2% correct responses, the score of Sound 8 was virtually the same, 80.8%. Sound 9 was the broadband sound and was expected to be the best localized, but Sound 8 showed that very similar localization could be obtained with a carefully selected complex tone.

4. Discussion

The anechoic room trials were conducted to select the most appropriate sounds for further trials in an aircraft cabin simulator. Trials within an aircraft cabin or simulator are essential to assess the potential use of directional sound within a realistic environment. Fixtures such as bulkheads, seats and overhead luggage bins affect the acoustics of a cabin and may influence the perception of sound; hence it is important to assess the extent to which such fixtures might influence passengers' abilities to localize the sounds. It would be prohibitively expensive and not reasonably practicable to carry out trials in an operational aircraft: instead, the trials are to be conducted within an aircraft cabin simulator.

The anechoic room trials provided interesting findings. Sound 9 was the sound that was most accurately localized overall. Since Sound 9 was the broadband sound, it had been expected that this sound would be the most easily localized. However, the localization properties of Sound 8, one of the complex tones, were very similar, and overall there was very little to choose between these two very different sounds. Withington (1999, p34) states that "only certain types of sounds are inherently localisable, and what is crucial is that they contain a large number of frequencies, that is broadband noise. Pure tones, simple tone combinations or narrowband noise cannot be localised". However, the results obtained in the anechoic room trials have shown that carefully designed combinations of tones, as realised in Sound 8, can be localized as well as broadband noise.

Carefully designed combinations of tones are likely to prove just as effective as broadband noise when used to guide people along a route or towards an exit. Furthermore, such combinations of tones have definite pitch and timbre and are more distinctive and recognisable than broadband noise. It is likely that such distinctive complex tones will penetrate broadband background noise more effectively than a broadband noise evacuation signal, for the same overall signal power. A convincing case can therefore be made that a complex tone is a good alternative to broadband noise, and may be better in some respects. Further work will now be necessary to assess the extent to which different sounds can be localized within an aircraft cabin, and to determine the influence that cabin fixtures and fittings may have on the perceived direction of sound.

5. Conclusions

Of the signals tested, broadband noise was the most effectively localized. However, the tests have shown that it is possible to produce complex tone signals that are virtually as effective as broadband noise for localization. Furthermore, complex tone signals have advantages over broadband signals. Complex tone signals have definite pitch and timbre, are more distinctive and recognisable as evacuation or warning sounds than broadband noise, and will generally penetrate background noise more effectively than a broadband noise signal for the same overall signal power. A well designed complex tone signal should therefore provide a good alternative to broadband noise signals in systems for guiding people to exits, and may be better in some respects.

Further tests are necessary to assess the extent to which different sounds can be localized within the more realistic environment of an aircraft cabin, and to determine the influence that cabin fixtures and fittings may have on the perceived direction of sound.

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