Life Saving Applications of Directional Sound

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Preface

Deborah Withington is a Professor of Auditory Neuroscience at Leeds University (UK). Her chair was awarded for excellence in Research and Innovation. Her research over 20 years has investigated directional sound and human responses to sound. She moved from the National Institute of Medical Research (London, UK) to Leeds University in 1990. After initial sponsorship from the Medical Research Council she was made a Senior Medical Research Council Fellow in 1993. In the last 8 years her attention has focused on life-saving applications of directional sound, particularly its role in evacuations. She has published many research articles and book chapters on directional sound in real world use. She has spoken at many international conferences (in the year 2001 these included the NFPA, the International Symposium on Aviation Emergencies and the International Fire and Cabin Safety Conference). In 1994 she co-founded Sound Alert Ltd. as a University Spinout Company based on the patented technology of directional Sound. In 1997 Sound Alert was given the prestigious Prince of Wales Award for Innovation.

The University of Leeds is among the top ten research universities in the UK. It has some 3,000 researchers, including postgraduates. The variety of research activity extends across all faculties and departments, often crossing traditional subject boundaries. Interdisciplinary research is promoted through some 58 home departments and some 58 research centers and institutes. Businesses ranging from small local companies to major multinationals benefit from collaboration with Leeds researchers.

Key Issue

Imagine the scenario of a smoke-filled building. The fire alarm is ringing, telling you to leave immediately. The most important question facing you is: Where do I go to find a safe exit?

In most buildings, exit routes are identified by visual means, exit signage. All signage is immediately obscured with even low levels of smoke. Exits can also be hard to find in visually cluttered areas, such as an airport or shopping mall. An obvious solution is the use of sound since people hear perfectly well even in smoke. If sound is utilized to identify exits, then it is vital that people can instantly pinpoint where the sound is coming from — in other words, directional sound. To be directional, the sound must be broadband[2] in composition, containing the majority of frequencies from the human hearing range.

One of the most frightening experiences is to be lost and disoriented. Being truly disoriented may be relatively rare, but it may happen to any of us at any time. As a newcomer to an unfamiliar building, you will most likely experience some degree of stress or anxiety that progressively worsens as your disorientation increases. As time passes, however, by looking at signs, asking others for directions and exploring your environment, you are able to move through it efficiently.

None of us, however, is totally familiar with all environments. Many behavioral studies have repeatedly shown that one of the most natural instincts in the event of a fire is people evacuate a building by the route through which they entered. This is rarely the quickest or most appropriate way. Many people fail to spot nearby exits and in some cases walk straight past visible fire exits. The repercussions of such actions have been severe.

Given that vision is our primary mode of perceiving our environment (83% of what is learned is through the eyes), it is not surprising that the majority of emergency egress aids, such as emergency lighting, signage, color coding walls and doors, and photoluminescent guidance strips, are solely visual based.

How effective are such aids when the part of the building you are in is completely or partially filled with smoke or if you are visually impaired?

Recommendation

Sound Sources as Way-Finding Aids

It is clear that this reliance upon visual means just isn't good enough in modern evacuation practice. It is imperative that another sensory method is activated, therefore, the use of sound becomes the obvious solution. At Leeds University, such a way-finding aid has been researched and developed by Deborah Withington, Professor of Auditory Neuroscience, with extensive field trials showing it to offer fast, efficient evacuation for sighted, visual and learning-impaired users.

System Sensor has incorporated this new egress technology researched by Leeds University into Directional Sound units[3]. This is a broadband, multi-frequency sound. The sound source is easily and quickly located by our ears, making it ideal for rapid evacuation applications. Triggered by existing fire detection systems, Directional Sound positioned at carefully chosen locations guide people along escape routes. They can also guide people up or down stairs.

Generally, all uses of sound in an emergency evacuation are provided in the form of an "alarm," which alerts people to the presence of imminent danger. General evacuation alarms give no information concerning the direction to, or location of, the nearest exits. Even if the current evacuation alarm devices were placed over exit doors, they would still be impossible to locate because these types of sounders are not directional. To understand why the current devices would not suffice as exit locators, it is necessary to describe how we manage to locate sounds.

The superior colliculus[9] (SC) part of the mid-brain plays a vital role in the detecting of as well as responding to a sound source. Neurophysiologists studying the properties of neurones in the SC, together with psychoacousticians[8] studying human responses to sound, have enabled us to understand how the brain processes information relating to a sound source. It has long been recognized that localizing a sound source requires a vast amount of neural processing. Only certain types of sounds are inherently directionally identifiable. What is crucial is that they contain a large spectrum of frequencies, that is, broadband noise. Pure tones, simple tone combinations of narrowband noise cannot be localized.

We hear a vast range of frequencies, from approximately 20Hz to 20,000Hz (Hz = Hertz). There are three main types of information that allow the brain to directionalize sound. The first two are known as binaural[1] cues because they make use of the fact that we have two ears, separated by the width of our head. A sound that emanates from either side of the mid-line will arrive first at the ear closest to it and will be loudest at the ear closest to it. At low frequencies the brain recognizes differences in the arrival time of sound between the ears (interaural time differences[6]), and at higher frequencies the salient signal is the loudness/intensity difference between the sound at each ear (interaural intensity differences[5]) (Figure 1).

For single frequencies, these cues are, however, spatially ambiguous. The inherent ambiguity has been described as the "cone of confusion." This arises from the fact that for any given frequency there are numerous spatial positions that generate identical timing/intensity differences. These can be graphically represented in the form of a cone, the apex of which is at the level of the external ear. The cone of confusion is the main reason for our not being able to localize pure tones.

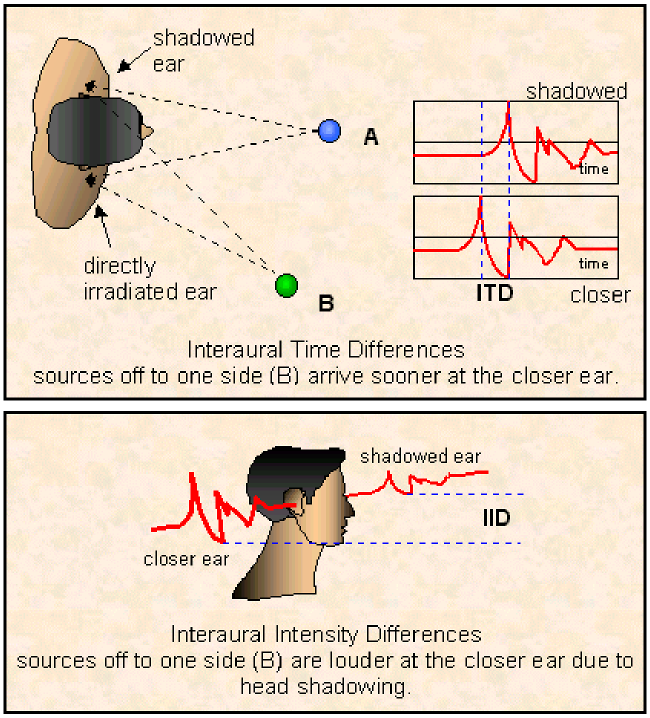

Figure 1: The localization cues of interaural time and intensity differences

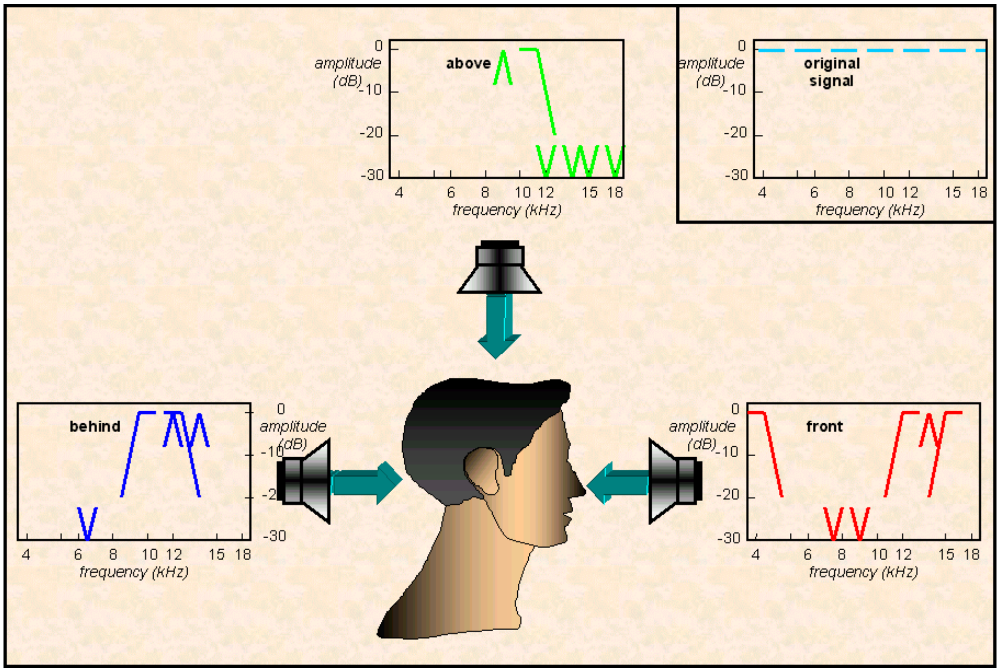

Figure 2: Examples of frequency dependent attenuation for sources in front, above and behind a listener*.*

The final piece of sound localization information processed by the brain is the head-related transfer function[4] (HRTF). The HRTF refers to the effect the external ear has on sound. As a result of passing over the bumps or convolutions of the pinna[7], the sound is modified so that some frequencies are attenuated and others are amplified (Figure 2). Although there are certain generalities in the way the pinna modify sound, the HRTF is unique to each individual. The role of the HRTF is particularly important when determining whether a sound is in front of or behind us. In this instance the timing and intensity differences are negligible, and there is consequently very little information available to the central nervous system on which to base this decision. To locate the direction of a sound source, the larger the frequency content to overcome the ambiguities inherent to single tones, the better the accuracy.

Analysis

Directional Sound and Evacuation Tests

There are many examples of applications where Directional Sound dramatically improves safety. One of the most important is in evacuation guidance. Directional Sound has applications in buildings and other situations where emergency egress lighting is currently positioned. The signals can be used to locate exit points and for guidance in complex evacuation routes such as from a central core of a large footprint building.

The use of Directional Sound has been tested in a variety of situations. The first tests took place in a relatively large television studio on the campus of Leeds University. Subjects were placed in the studio filled with artificial smoke and filmed with a thermal imaging camera. Relying primarily on their memory of the immediate environment and on touch, an individual took some 3 minutes and 50 seconds to find a conventional emergency exit sign. In contrast, when rapid bursts of broadband noise were played through output devices immediately adjacent to the exit, the same individual took 15 seconds to find the way out.

Complex routing tests

A deserted school building was used to test Directional Sound units placed at many direction, decision-making points and staircases. Having filled the school with artificial smoke, each subject was taken to a starting point on a first floor location via an external emergency escape staircase. Subjects had no prior knowledge of the building or the sound of the directional sound units. The route was marked by directional sound units at strategic points (mainly above fire doors). At one point, a flight of stairs led upwards, and a sounder was designed that had rapidly pulsing broadband noise and an upwardly sweeping “melodic” complex which denoted “going up the stairs.” At another point, the main staircase descended to the final intended exit. A “down sweep” in this signal gave the impression of “going down the stairs.” As signals progressed from the starting point to the final exit, their pulse rate increased to denote getting closer to the exit.

Once again, the effectiveness of the Directional Sound units was unquestionable. None of the subjects in any of the trials took a wrong turn. All subjects reported that the up and down tones informed them not only of the presence of a staircase but also of the intended direction of travel. They intuitively understood the “associative meaning” within the sound. Evacuation times were close to that which would have been expected under ideal visual conditions with prior building knowledge.

From these studies, it is clear that the Directional Sound units proved to be a crucial aid for users under visually impaired conditions. By providing directional information, the signals remove the need for having prior experience with the environment, reducing hesitancy and totally eliminating way-finding errors. Overall, evacuation time was reduced substantially (by more than two-thirds in many cases).

Left or right tests

In one pilot study, participants were led into a room and given the choice of turning to an exit at the right or left at equal distances. Each exit was equipped with a Directional Sound unit set at 93dB(A) at 3.2 feet and a conventional emergency exit visual sign. The sounder and sign units were 30.2 feet apart. The aim of the study was to direct the participants to a safe exit.

Participants were invited to take part in one of eight situations. The first looked at how people respond with just visual exit signs. In the next four scenarios, there were two Directional Sound units and lights, which led participants to one of the safe exits, either left or right. To determine the degree of training needed to follow the sound system, participants were told to evacuate as quickly as possible and either: 1) told nothing more, 2) were informed about the sound, 3) shown the layout of the room and the placement of Directional Sound units, or 4) had the same information as group 3, plus they had already been through the smoke before. In the final three tests, participants were told to evacuate as quickly as possible and were either faced with: a conflict – there was one visual exit sign on one side and a sounder on the other side; no conflict – there was one target exit with both a sounder and sign unit; or marshals – two exits gave participants speech directions, with the target exit saying, “Come this way,” and the other saying, “This way is dangerous.”

Participants told to find the exit by following visual exit signs only when in a smoke-filled room took up to 105 seconds (average 67.8) to reach a safe exit. Participants given Directional Sound and visual exit signs to follow and were trained on the sound of the Directional Sound units took as little as 7 seconds. Interestingly, participants who were just given visual exit signs to follow when in a room without smoke took as long as 12 seconds (average 8.8) to reach an exit. Those given Directional Sound units and visual exit signs to follow when in a room without smoke and were also trained on the sound of the Directional Sound units took as little as 6 seconds (average 7.2) to reach a safe exit.

Multiple choice in open space tests

In these experiments, participants were led through a door into the center of a room and given the choice of one of three exits. Directional Sound units and visual sign units were placed at exits A and B; only a visual exit sign was at exit C. The Directional Sound units and sign units were around 13.1 feet from the participant, and the Directional Sound units were set at 93 dB(A) at 3.2 feet.

Participants took part in one of seven situations. The first four scenarios looked at the degree of training needed to follow the sound system. Participants were told to evacuate as quickly as possible and were either: 1) given no further information, 2) informed about the sound, 3) shown the layout of the room and the placement of Directional Sound units or 4) had the same information as group 3, plus they had been through the smoke before. In the following trials, there were two Directional Sound units and lights at points A and B, and at point C there was a visual exit sign. Initially, the target exit was A or B, then exit C became the target exit.

The following tests had one specific target exit. The participants were told to evacuate as quickly as possible and were either faced with: a conflict — there was one visual exit sign at point A and one Directional Sound unit at point B; no conflict — there was one target exit, i.e. Directional Sound unit and sign unit at one exit; or marshals — two exits gave participants speech directions, with the target exit saying, “Come this way,” and the other saying, “This way is dangerous.”

Participants in a smoke-filled room who were just told to find the exit took as long as 22 seconds (average 14.5) to reach a safe exit, compared to an average of 5.5 seconds for those in rooms without smoke. Participants given Directional Sound units and visual exit signs to follow and were trained on the sound of the Directional Sound units took as little as 7.3 seconds to reach a safe exit. Participants given Directional Sound units and visual exit signs in a room without smoke and were trained on the Directional Sound took an average of 4.9 seconds.

Complex maze tests

In experiments testing complex mazes, participants were led through a series of rooms to find a safe exit. The maze was equipped with Directional Sound units and visual signs to guide participants to the end of the maze, i.e. the target exit. The aim of the study was to direct the participants to a safe exit. The Directional Sound units were set at 93 dB(A) at 3.2 feet.

Participants who were only told to find the exit when in a smoke-filled room took as long as 124 seconds (average 97.8) to reach a safe exit. In contrast, participants who were given Directional Sound units and visual exit signs to follow and were trained on the sound of the Directional Sound units took as little as 13.3 seconds (average 51.3) to reach a safe exit. Participants who were only told to find the exit without smoke took as long as 14 seconds (average 9.7) to reach a safe exit. Those who were given Directional Sound units and visual exit signs to follow took as little as 7 seconds (average 10.86) to reach a safe exit.

One of the interesting facts that stems from the pilot trials is that using sound and lights together results in faster evacuation than using lights alone. Research has shown that the area of the brain that responds to spatial sensory information (the superior colliculus), which also initiates the response to the sensory stimulus, contains cells that are tuned to more than one sensory modality. These neurones respond to light by itself and also to sound alone. However, when light and sound are presented together, the response of these cells is far greater, sometimes more than 1,000% better, than the summation of the response to either modality alone.

Characteristics of Directional Sound

Directional Sound units are NOT intended to replace traditional fire alarm evacuation sounders. In all the building testing performed the standard notification appliances were used (85dBA horn and 75 candela strobe). The fire alarm plays an important role in alerting people to the potential threat. Once someone has made the decision to evacuate, the fire alarm ceases to fulfill a function. Anyone leaving a building then needs to know how to find an exit. The fire alarm sound itself would be unsuitable for use over an exit. It is a narrowband sound and therefore not possible to localize. We can listen to many different sounds simultaneously and decide which one to attend to based on the frequency of the sounds.

Conclusions

There is a huge versatility in the number of applications that would benefit from the use of Directional Sound units, the most striking use is in building evacuation. As one of the largest manufacturer's of fire detection and notification appliances in the world, System Sensor's commitment is to serve the needs of the growing worldwide fire alarm market. Mainly by the public's awareness emergency evacuation is getting better, however it is still a problem to solely address the visual needs of occupants when it is likely that these visual means will be made obscured in the event of an emergency. Only through a combination of both visual and auditory way-finding aids will optimal safety be achieved.

Definitions

1. Binaural - perception of sound with both ears

2. Broadband frequency – a sound containing all of the frequencies across the human hearing range 20Hz – 20KHz

3. Directional sound – a sound containing the broadband frequency to aid egress

4. Head related transfer function – the result of the external ear modifying sound so that some frequencies are attenuated and others are amplified

5. Interaural intensity differences – sources off to one side are louder at the closer ear due to head shadowing

6. Interaural time differences – sources off to one side arrive sooner at the closer ear

7. Pinna – the largely cartilaginous projecting portion of the ear

8. Psychoacoustician – the scientific study of the perception of sound

9. Superior colliculus – portion of the mid-brain that plays a vital role in detecting of and the response to a sound source

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