Use of Directional Sound for Ship Evacuation

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Abstract

Imagine the scenario of a smoke-filled ship. At present evacuation routes are signed by visual means. Visual signage is immediately obscured with even low levels of smoke, so it is vital that we develop an alternative means of identifying evacuation routes that does not rely solely on vision. An obvious solution is the use of sound since we hear perfectly well even in smoke. If sound is utilized to identify exits then it is vital that we can instantly pinpoint where the sound is coming from, in other words directional sound. To comply with being directional the sound must be broadband.

Modern ships are complex structures whose very design and layout can hinder rapid evacuation. Familiar thoroughfares may be hard enough to navigate in the unusual conditions of an emergency evacuation but add an unfamiliar emergency route to the situation and the difficulties are compounded. Even worse, add smoke to the passageway, making it difficult or impossible to see, and the situation can rapidly escalate.

Ten years have passed since the official Norwegian report on The Scandinavian Star, where the investigating committee recommended that audible signals be installed by the exit doors in escape routes on board passenger ships. Surely there doesn't have to be another disaster before this recommendation is finally implemented.

Introduction

One of the most frightening experiences that we ever face is to be lost and disoriented. Under such circumstances, our ability to process and store environmental information deserts us and, because most of us are dependent upon others knowing their way, or 'information' such as signs pointing the way, our very survival may be threatened. Being truly disoriented may be a relatively rare phenomenon, but given the right series of cataclysmic conditions, it may happen to any of us at any time.

For example, as a newcomer to an *unfamiliar* building such as a department store, hotel complex, or university campus, 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 begin to establish a series of inherent spatial relationships that were not apparent when you first entered the building. The more you actively explore, go the wrong way, ask directions etc., the more environmental information you collect, this information begins to organize itself into a mental representation of the environment. At a certain stage in this 'mental' development, you may class yourself as being a familiar user of the building, or in other words, you are able to move through it efficiently, going from one place to another without too many problems. A similar situation may occur on board a cruise liner for example. You are shown your way to your cabin and over time explore different routes that take you to the restaurants, swimming pool and other frequently used areas.

None of us, however, is *totally* familiar with all environments we enter, and this is most evident when an emergency situation arises. Many behavioural studies have repeatedly shown that one of the most natural instincts in the event of a fire is that people evacuate a building by the route through which they entered. More often than not, 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! On board a ship you may remember the route you last took or one you frequently use.

The repercussions of such actions have, in several cases been severe. Certain circulation routes (generally those used for normal, everyday movement) experience a higher population flow than they were designed for, leading to overcrowding and a slowing down of the evacuation process. As a consequence, some occupants are exposed to deadly smoke, fumes and flames.

Modern ships and ferries are complex structures whose very design and layout can hinder speedy evacuation. Familiar thoroughfares may be hard enough to navigate in the unusual conditions of an emergency evacuation but add an unfamiliar emergency route to the situation and the difficulties are compounded.

In April 1990 a fire raged through the Scandinavian Star ferry as it coursed through Norwegian waters on an overnight voyage from Oslo to Copenhagen. Of the 500 passengers and crew on board, 158 died including 29 children. Bodies were found below deck piled up in the corridors close to emergency exits, in cabins and even in the showers. Part of the investigation concentrated on the issue of why people died even though some were so close to emergency exits. Many survivors claimed that it was impossible to see the emergency exits in the corridors when these were full of smoke. In an attempt to understand what went so tragically wrong on board the Scandinavian Star, the Norwegian Fire Research Laboratory performed a series of evacuation trials on a reconstructed section of the Scandinavian Star. Using existing emergency signage provision, it was found that 40% (of their test subjects) could not find the emergency exit.

They either passed it, or tried to get out through the wrong door, and some turned round on the way out. In their summary the Norwegian researchers stated, "We do know that emergency lighting and marking signs do not help to distribute people among the evacuation routes available."

The Norwegian official report on the Scandinavian Star Disaster[1] stated "The committee recommends that a requirement be introduced that audible signals with a sound that clearly distinguishes them from the alarm bells be installed by the exit doors in escape routes on board passenger ships, as directions for escape in conditions of reduced visibility".

Current Strategies for Evacuation Route Marking

Given that vision is our primary mode of perceiving our environment, it is not surprising to find that the majority of emergency evacuation aids, such as emergency lighting, low location lighting, signage, colour coding and photoluminescent guidance strips are solely visual based. How effective are such aids when the environment you are in is completely occluded by smoke? It is clear that existing emergency way-finding provision offers very limited means by which to escape! Tests by the BRE show in only 3% smoke visual exits are not visible within 1.5m. It is a safe assumption that, ***unless*** the victim of a fire situation knows exactly where the exits are, he or she will waste valuable seconds or minutes searching by touch alone. Given the rapid rate at which fires can develop, time becomes the overriding critical factor in emergency evacuation and survival.

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

The present role of sound in emergency evacuation

Generally, all uses of sound in emergency evacuation are provided in the form of an "alarm" which merely alerts people to the presence of imminent danger. Irrespective of whether this information is provided by conventional alarm tones or through more sophisticated speech based alert mechanisms, alarms give absolutely no information concerning the direction to, or location of, the nearest exits. Even if such alarms were placed over exit doors, acting as directional beacons, they would still be very difficult to locate. To understand why these devices would not suffice as exit locators, it is necessary to describe, in some detail, how we manage to locate sounds in space, including the type of signal necessary for accurate localization.

Sound Localization

The ability to localize a sound source is an evolutionary prerequisite for survival. For example, when hearing the crack of a twig as a predator approaches, there is simply not time to wait and look around to check where the sound is coming from. To survive we must react instantly, as soon as the audible signal is received. Similarly, for predators, a rustle of leaves may indicate where their potential prey is hiding, and locating that position will determine whether or not they eat on that occasion. It is, therefore, safe to conclude that pinpointing sound is something we do well. In reality we can localize a sound to an accuracy of about five degrees, given the right type of sound[2]. This level of accuracy is less than that for visual spatial acuity, but more than adequate for survival purposes.

There is one particular part of our central nervous system that plays a vital role in the detecting of, and equally importantly, the response to a sound source. This area is part of the mid-brain and is called the superior colliculus (SC) [3]. Neurophysiologists studying the properties of neurones in the SC together with psychoacousticians studying human responses to sound have enabled us to understand how the brain processes information relating to a sound source and, importantly, what type of sound is needed for a degree of accuracy to be achieved. It has long been recognised that localizing a sound source requires a vast amount of neural processing [4]. Only certain types of sounds are inherently localizable and what is crucial is that they contain a large spectrum of frequencies, that is broadband noise. Pure tones, simple tone combinations or narrowband noise cannot be localized. To understand why this is the case, the cues given by sound, recognised by the brain, must be considered.

Localization cues

We can hear a vast range of frequencies, from approximately 20Hz to 20kHz, although this range diminishes as we age. There are three main types of information that allow the brain to localize sound. The first two are known as binaural 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 also be loudest at the ear closest to it. At low frequencies the brain recognises differences in the time of arrival of the sound between the ears (ITD), and at higher frequencies the salient cue is the loudness/intensity difference between the sound at each ear (IID). The use of these two types of cue is known as the 'duplex' theory and was proposed by Lord Raleigh as long ago as 1877 (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 [5,6].

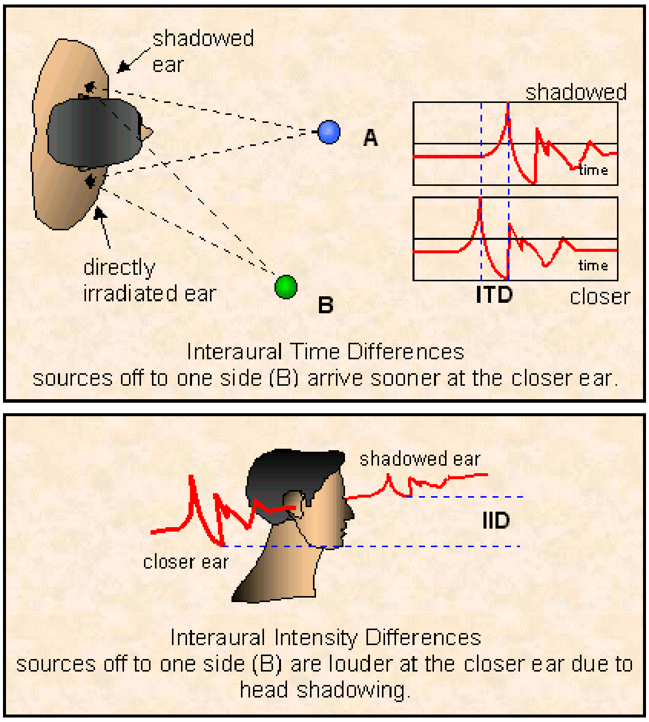

Figure 1: The localization cues of interaural time and intensity differences.

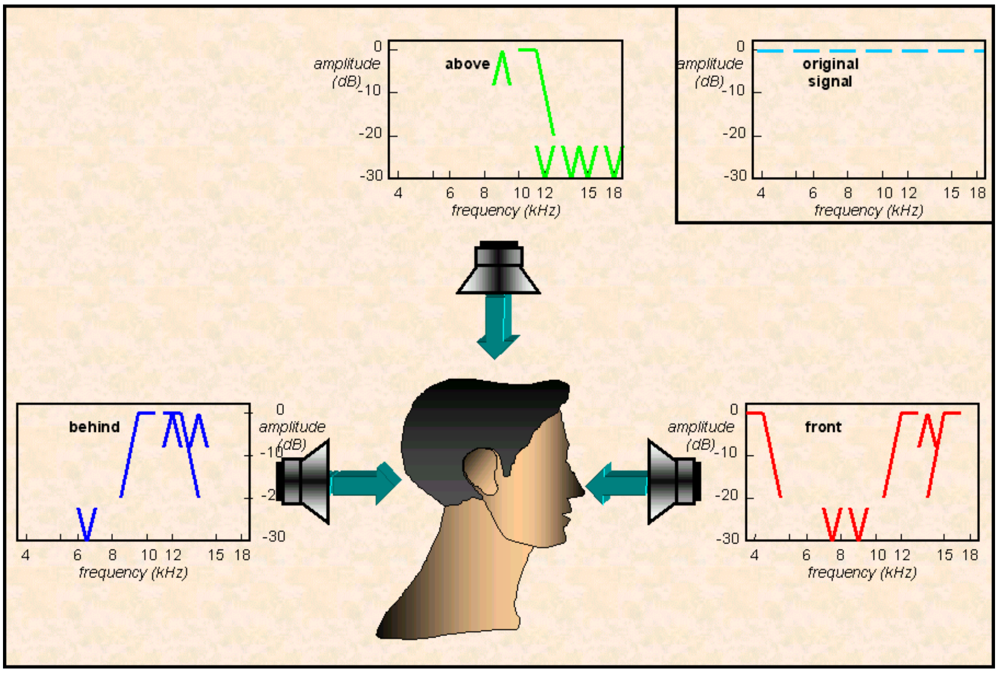

Figure 2: Examples of frequency dependent attenuation for sources in front, above and behind a listener.

The final main piece of information processed by the brain regarding sound localization is called the head-related transfer function (HRTF) [7]. 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, 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 sound is modified by the pinnae, the HRTF of any one person is unique to that individual. The role of the HRTF is particularly important when we are trying to determine whether a sound is immediately in front of, or directly 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 a decision of 'in front' or 'behind'. So, to locate the direction of a sound source, the larger the frequencies content, to overcome the ambiguities inherent to single tones, the better the accuracy.

Directional sound and evacuation

Evacuation beacons, using directional sound, have applications in buildings, ferries, ships, aircraft and many other situations where emergency lighting is currently positioned. The beacons can be used in two ways;- firstly, as perimeter marking and secondly for complex routing in which the public must be guided from the centre of a labyrinthine structure. The use of directional sound evacuation beacons has been tested in a variety of situations.

1.Simple scenarios -The first series of tests took place in a relatively large television studio situated in the confines of the campus of Leeds University. The studio was filled with artificial smoke and subjects were placed in the studio and filmed with a thermal imaging camera. Relying, primarily, on their memory of the immediate environment and on touch, it was found that an individual would take some 3 minutes and 50 seconds to find a conventional emergency exit sign. In contrast, when rapid bursts of broadband noise were played through an evacuation beacon immediately adjacent to the exit (which in this case was acting as a perimeter marker), the same individual traversed the wide open space taking 15 seconds to find the way out.

2. Complex routing - Complex routing was tested in a different environment, a deserted school building. A complex route was devised which would test the evacuation beacons to their fullest, including many directional decision making points and also staircases (Figure 3). Subjects in these trials included sighted, visually impaired individuals and children. Having completely filled the school with artificial smoke, each subject was taken to a starting point on a first floor location. They were taken to the start point via an external emergency escape staircase. By doing this subjects had absolutely no idea of the route they were about to go through. In addition, they had no prior knowledge of the sound of the evacuation beacons. Once ready all beacons and the building's fire alarm were activated and each subject, or group of subjects, entered into the smoke. Essentially, only 4 egress beacons placed at strategic points (mainly above fire doors) on the way marked the whole route. At one point on the route, there was a small flight of stairs which led upwards to a mid-level in the building, and a beacon was designed that, as well as having rapidly pulsing broadband noise, also included an upwardly sweeping "melodic" complex which indicated to the subject "go up the stairs". At another point en route, there was the main staircase that descended to the final intended exit. Similar to the "up sweep" a "down sweep" was designed into this beacon giving the impression of "going down the stairs". As beacons progressed from the starting point of the experiment to the final exit, their pulse rate increased. This concept relies on human intuition with regards to faster events signaling nearing a final goal; the same concept that is used on rumble strips when approaching a roundabout.

Once again, the effectiveness of the beacons was unquestionable. None of the subjects in any of the trials took a wrong turning or ended up in any room that they were not supposed to enter. All subjects reported that the implementation of the melodic complexes indicating “up” or “down” information, informed them not only of the presence of a staircase but also of the intended direction of travel. As previously mentioned, they were not briefed as to the meaning of such tonal sweeps but intuitively understood the “associative meaning” within the sound. Finally, evacuation times were basically reduced close to total travel times that would have been expected under ideal visual conditions with prior knowledge of the building. Indeed, it was interesting to note subjects’ responses when the building was eventually cleared of smoke and they were asked to progress through it once again. Without the aid of the navigation beacons and with full visibility, several subjects got lost en route. Even though they had been through it only a few minutes earlier.

From these studies, it is clear that the beacons proved themselves to be a crucial aid for all users under such visually impaired conditions. By providing directional information the beacons 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).

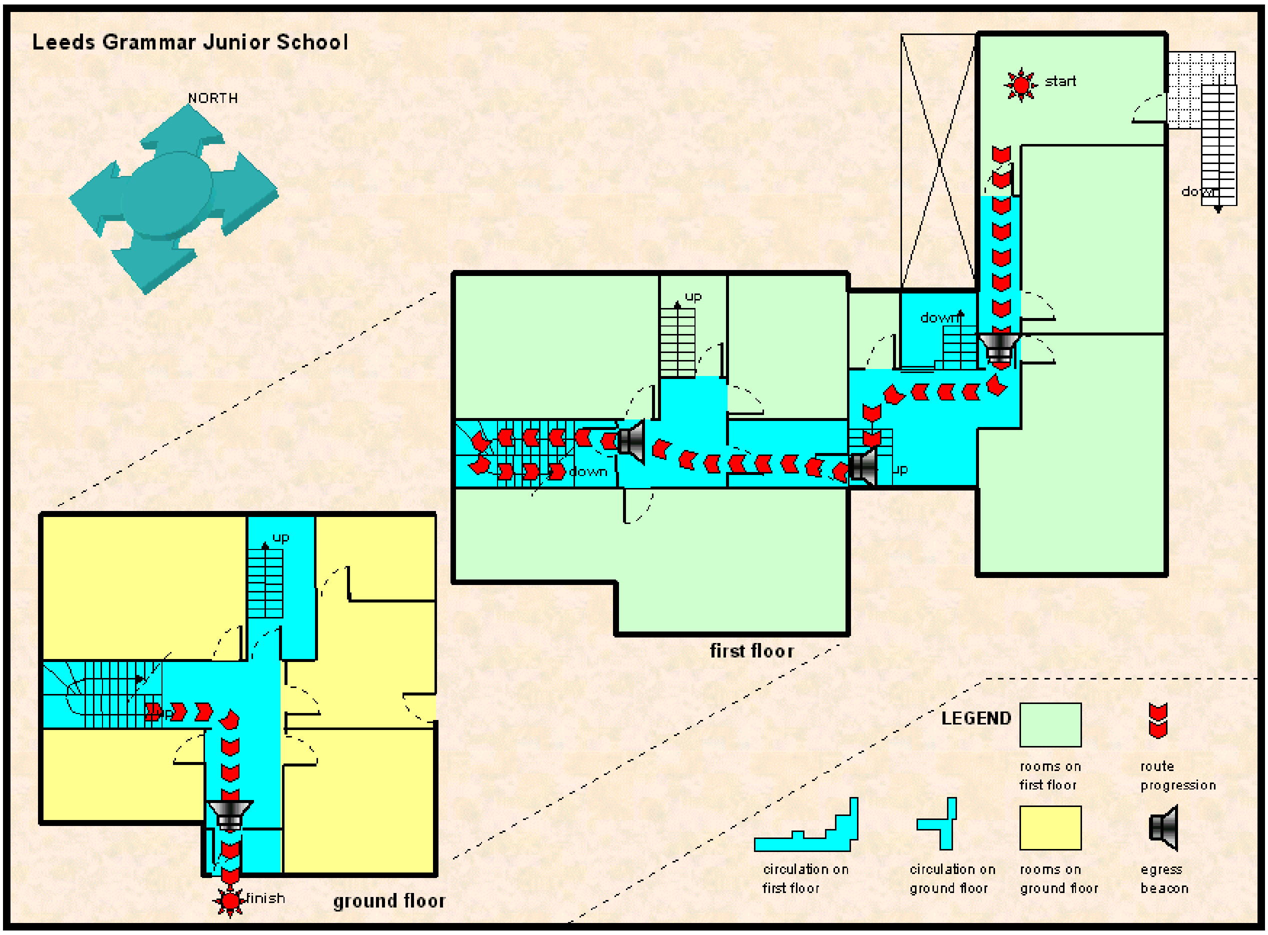

Figure 3: Plan of the school route

Ferry evacuation

In January 2000 we were able to put the beacons to a rigorous test on board a ferry in dry dock [8]. Twenty volunteers were used in the experiments. The volunteers were led, by different routes, to two cabins in the centre corridor of an accommodation section comprising three parallel corridors. Each cabin was filled with people who had entered it using different routes. The ship's normal lighting remained on throughout the experiment. Both groups were told that there was going to be one safe route that they could follow to escape from the smoke that would shortly fill the corridors. Some of the potential exit routes would be "non-viable" (i.e. blocked) due to the location of the simulated fire. After filling the corridors with smoke the first group was let out of their cabin in pairs, at five seconds intervals. As you would expect, about half went each way - left and right. Those who turned left found a blind alley and a blocked exit and had to retrace their steps, potentially fatal in a real fire. Those that went right reached a T-junction and had to choose, left or right. Again, about half turned each way. The people turning right found a blocked exit and had to retrace their route. Eventually, due to the fact that it was theatrical, as opposed to real, smoke, all got out.

More smoke was laid down in the corridor before the second part of the experiment began. The directional sound evacuation beacons were then activated. The remaining group in the cabin was briefed that the beacons were located on the exit route and then released in the same way as before, i.e. pairs at five-second intervals. All turned immediately right and then immediately left at the T-junction and were out in about one third of the time it had taken the first group. No one went the wrong way. There was considerable excitement amongst the volunteers afterwards with volunteers who did not have the beacons to guide them expressing how disorientating and confusing their experience had been. Conversely, those who had used the evacuation beacons made comments like "I couldn't believe how clear and obvious the sound beacons were - I had no doubt which way to go."

Behavioural database

Before the directional sound beacons are used extensively throughout the world in different applications, it is important to be able to state how they function in different scenarios (such as unusual geometric configurations) and how they interact with existing emergency signage and evacuation procedures (eg fire marshals). Data of this nature will enable us to specify optimal configuration of the beacons and refine installation guidelines. A study is currently underway, in conjunction with Professor Galea (Greenwich University, U.K.), to obtain these data in the building environment.

Following a presentation to IMO earlier this year trials in the marine environment have been agreed, with the help of the MCA. The trials will take place on board ships and look at large areas of open space, corridor/cabin situations, stairwells and routing to evacuation points not normally used by passengers.

Characteristics of the sound beacons

It must be made clear that the sound beacons are NOT intended to replace traditional fire alarm sounders. In the case of a fire on board a ferry, for example, the fire alarm will still sound. Indeed, in all the building and ferry testing we have undertaken the fire alarm has been used. The fire alarm plays an important role in alerting people to the potential threat, whether it is a fire or other problem. Once someone has made the decision to evacuate the fire alarm ceases to fulfil a function, the next most important decision for any one leaving a building is where to find an exit. The fire alarm sound itself would be entirely unsuitable for use over an exit. It is a narrowband sound and thus, extremely difficult to localize. We are capable of listening to many different sounds simultaneously and make the decision which one to attend to based on a subconscious analysis of their importance.

The sound beacons are currently available in two forms. Either as a stand-alone beacon or as a combined emergency exit light/ sounder unit. The beacons have 2 settings; 93 & 99 dBA @1m and come with a range of pulse pattern options (including "up" and "down" sounds). Installation of the beacons is based on a similar process to that involved in identifying the location for exit signs. The same guidelines for the installation of fire alarms can be applied to the broadband sound from the directional evacuation beacons. That is, there is a 20 dB attenuation through normal doors, 30 dB attenuation through fire doors and the sound reduces by 3 dB for every doubling of distance. Interestingly, our studies on the perception of broadband noise show that it is heard at far lower levels than a pure tone (up to 15 dBA difference), thus enhancing its efficacy.

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Author Biography

Deborah Withington is a Professor of Auditory Neuroscience. She has been based at Leeds University since 1990. In addition to her academic duties she is a Research Director for Sound Alert Technology plc, a Company spin out from Leeds University. Her main areas of research are the use of directional sound as a guide for way finding and the use of ultrasound as a navigational tool for the visually impaired.