

THE PSYCHOACOUSTIC BASIS AND IMPLEMENTATION OF DIRECTIONAL SOUNDERS

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Introduction

When new fire safety technologies appear the potential benefit of the technology will be a function of the effectiveness of existing technologies, and whether or not the new technology can fulfill a need or provide a safety enhancement at reasonable cost. One such new technology that holds promise as an enhancement to improve the utilization of exits and provide an effective means for wayfinding during an emergency building evacuation, particularly, under adverse conditions (smoke or darkness) is the technology of **directional sound**.

With any new technology there are a number of immediate questions to be answered... What is this directional sound and what is its purpose? Also, what indicates that the technology is valid and appropriate for use?

To begin, a directional sound device is a type of electronic signaling device that is installed as part of a building fire alarm system. When activated, it produces short bursts of broadband sound in a frequency range that is distinctive from simultaneously operating fire alarm sounders such as bells, or horns. The broadband sound pulses of directional sounders make use of our natural human ability to localize sound sources. The purpose of these devices is to help occupants in finding their way to an exit, refuge area or other means of egress by providing additional sound cues that can assist or aid occupants in locating escape routes without conflicting with the traditional fire alarm system notification appliances. It is important to note that directional sounders are not intended to replace or be a substitute for notification appliances required by building or fire codes.

An example installation of directional sounders is illustrated for the floor of a building in Figure 1 and at a doorway in Figure 2. The concept of using directional sound differs from that used for bell, horn or voice speaker installations. Generally these notification devices require placement at numerous locations in order to achieve the sound levels that can be heard and understood by occupants throughout all building areas. In a basic installation of directional sounders, the concern is not for establishing a minimum audible signal in all occupied building spaces. Rather, the focus is to provide sound cues to assist occupants in more easily locating the direction to a nearby exit or area of refuge when occupants are moving through the means of egress during an evacuation. Since sound has the advantage of penetrating in many directions such as around corners there is an inherent flexibility and efficiency in using directional sound compared to line-of-sight methods for marking exits.

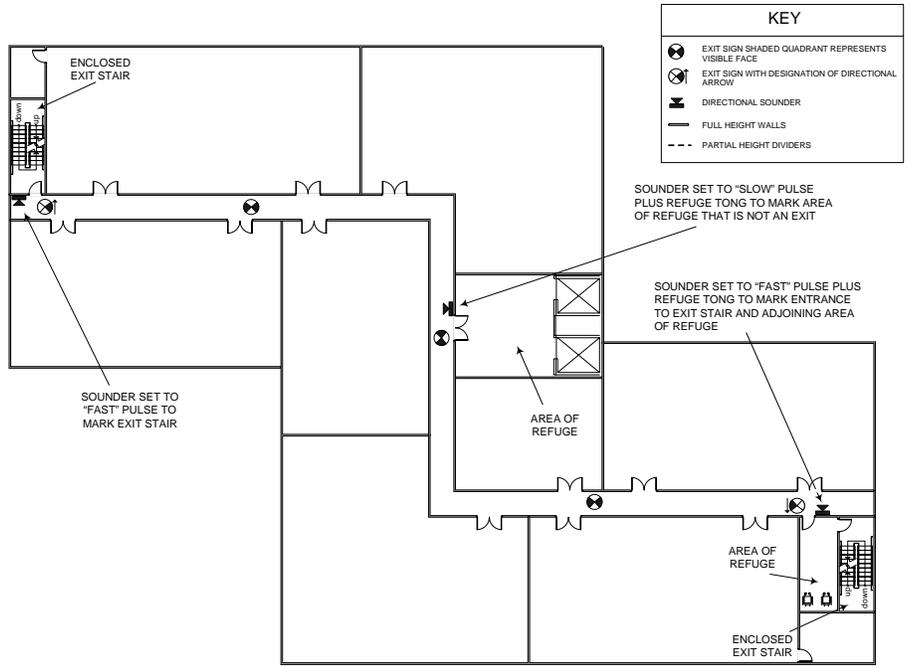


Figure 1. Example Application of directional sounders at exit stairways and areas of refuge. (Source: System Sensor ExitPoint Directional Sound Application Guide, Nov.2004)

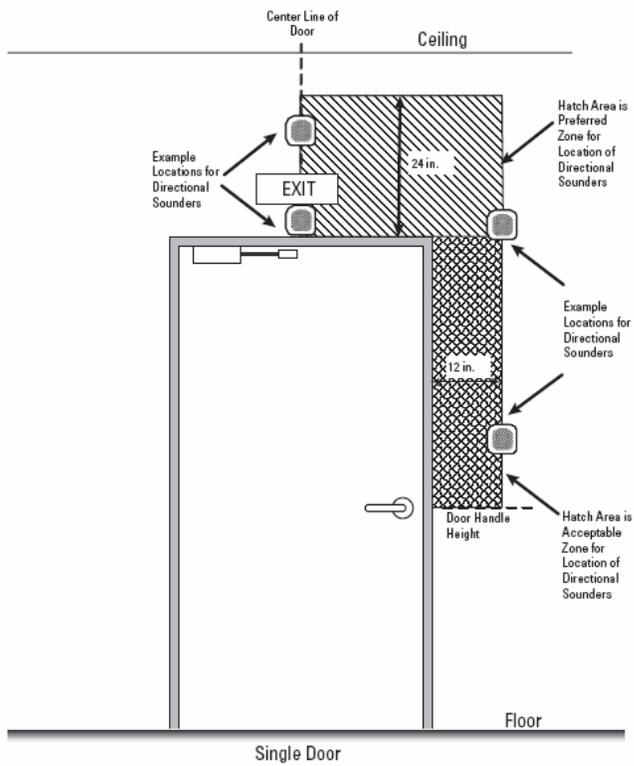


Figure 2. Directional sounders at an exit door. (Source: System Sensor ExitPoint Directional Sound Application Guide, Nov.2004)

To the reader the directional sound concept may appear interesting but not necessarily relevant. Considering that buildings are required to have exit signage to visually mark egress routes and protected exits would seem to address any issues or concerns for finding the exits during an emergency. History may indicate otherwise. The tragic 2003 Station Nightclub fire is a recent example. Approximately two-thirds of the occupants appear to have attempted to leave through the main entrance at the front of the building although other exits were available. The draft report of the Technical Investigation (Station Nightclub fire) by the National Institute of Standards and Technology (NIST) recommends for existing nightclubs that an increased factor of safety be achieved by providing improved means for occupants to locate emergency routes once standard exit signs become obscured by smoke.¹ Directional sound offers one possible solution to assist occupants in finding the exits under such adverse conditions. Additionally, there is evidence in the literature on human behavior that points to the possible low utilization of otherwise readily available and marked exits.

How Effective are Current Exit Marking Methods

Several human behavior studies have demonstrated that during an emergency building evacuation occupants will move and exit via a route that is familiar and known to the occupants. These studies conducted with fire survivors as well as through observation of evacuation drills, consistently show that available emergency exits are largely ignored or underutilized^{2,3,4}. It could be argued that this phenomenon of using a familiar exit is more likely to take place in buildings where most occupants are not familiar with the premises, such as visitors to a museum or a shopping center. However, residents of a high-rise apartment building or people who work in an office building may not have any experience with alternative means of egress than their daily route in and out of the building.

Although exit signs are placed above exit doors and along egress routes, as required by building and life safety codes, these signs do not always seem to assist occupants with finding exits during an emergency. This observed behaviour has been explained in terms of an established psychological concept known as 'learned irrelevance.' This concept considers that 'exit' signs have a 'learned irrelevance' which occurs when a person is continually exposed to a stimulus, such as an exit sign, but rarely needs to respond to the always present stimulus.⁵

The concept of learned irrelevance has been experimentally studied in the context of building evacuations by McClintock, et al. One experimental evaluation was performed to determine, if under everyday conditions do people notice and recall emergency exits. This experiment involved 500 persons chosen at random from people exiting a large, busy retail store having 14 emergency exits. The participants were asked "Did you notice any emergency exits in the store? If so, how many?" After answering these questions the participants were prompted to identify emergency exits using a schematic floor plan of the store. Significant was the fact that 75.2% of the participants did not notice or identify any of the emergency exits.

From this work by McClintock *et al.* was the suggestion that "Any new form of signage must not be susceptible to learned irrelevance and the only way to ensure this does not happen is to have a secondary signage come into play *only* when an evacuation is

necessary.” Based on this idea another experiment was conducted where six groups of sixty people evaluated six types of exit signs arrangements one of which was a standard illuminated sign with the addition of a blue flashing strobe light as an additional stimulus. Participants were asked to rate the various light arrangements based on ‘attention capturing ability’ (ACA) scale of 0 -6. In summary the flashing blue light had the best ACA scores. These observations and experiments point to the benefit of directional sound as a surrogate for exit signage. Directional sound offers not only an added stimulus, it’s acoustic characteristics provide an ‘attention capturing ability’ that extends beyond the line of sight to an exit-sign/flashing-light by adding the additional sensory mode of hearing that assists object (e.g. exit) localization.⁶ Also, directional sound is intended to operate only in conjunction with the fire alarm system during an evacuation. This satisfies the McClintock *et al.* observation that to avoid learned irrelevance a secondary cue should come into play *only* when an evacuation is necessary

Human Hearing and the Ear

To better appreciate how directional sound works requires some basic understanding of how human hearing works and how sound processing allows a listener to locate with surprising accuracy the source of the sound they hear. Detailed explanations of how the human ear works as a specialized mechanical system are available.^{7, 8} Human hearing involves both the functions of the ear and the brain. The ear is essentially a mechanical system that is extremely sensitive to very small changes in air pressure that are sound waves passing through air. Sound waves are the vibrations of the air particles resulting from the vibration of some other object such as a musical instrument, operating machinery, or person’s vocal cords.

As a mechanical system our ears have three primary parts (1) the outer ear, (2) the middle ear, and (3) the inner ear. The outer ear is the physically visible part and is technically known as the **pinna**. The pinna is pointed forward with curves and shapes that serve to catch sound and direct the sound along the ear canal to the **tympanic membrane** commonly called the eardrum. The ear drum is a thin but rigid skin boundary separating the outer ear from the middle ear. When sound reaches the eardrum it vibrates moving rapidly back and forth for higher frequency sound waves while moving back an forth larger distances for louder sounds.

The middle ear is an air filled cavity that houses three tiny bones (the **ossicles**). The first of these bones, the **malleus**, is connected to the center of the eardrum which results in the transfer of vibrations sensed by the eardrum through all three bones. The last of the three bones is the **stapes** that is attached to the **oval window** which is the point of connection to the inner ear **cochlea**, a fluid filled channel. A primary function of the ossicles bones is to amplify by a factor of approximately 20 the small pressure received from the eardrum. As the eardrum vibrates, so do the ossicles which allow the stapes to act as piston creating fluid waves in the cochlea that are representative of the sound waves sensed by the eardrum.

The inner ear cochlea is considered the most complex part of the ear. It takes the physical vibrations received by the sound waves and converts or translates them into nerve impulses that the brain can recognize as distinct sounds. The cochlea is a snail-

shaped structure of three fluid filled tubes separated by sensitive membranes. Fluid waves moving along the **basilar membrane** can stimulate thousands of fibers that have different resonant frequencies. The **organ of Corti** is a structure containing thousands of tiny hair cells that lies on the surface of the basilar membrane and extends across the cochlea. When a fluid wave excites a resonant frequency the membrane releases a burst of energy that moves the organ of Corti hair cells at that point which in turn sends an electrical impulse through the cochlear nerve to the brain. The cochlea sends only raw data which the brain as a complex computer must process, analyze and interpret. This neural processing is incredibly fast and accounts for our human ability to readily, and easily detect the location of a sound source.

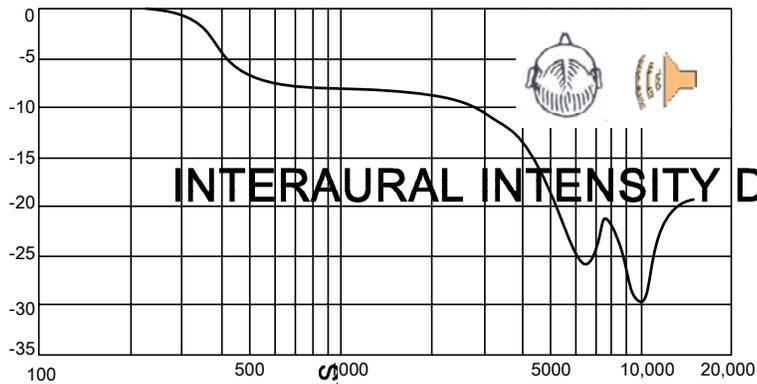
Pinpointing the Location of Sound

The psychoacoustic ability of human hearing as a mechanism for locating sound sources has been studied in great detail and numerous technical sources and complex studies document and explain the basis for human sound localization.^{9,10,11} Several basic factors are recognized to account for our ability to pinpoint with surprising accuracy a given sound particularly if it is broadband sound.^{12, 13}

The anatomy of the pinna or outer ear and the fact that our ears are separated to each side of the head allow for subtle sound differences that provide the binaural cues important for locating a sound source. These binaural (two ear) cues are:

- Interaural time differences (ITD)
- Interaural intensity differences (IID)
- Head related transfer function (HRTF)

Figure 3 illustrates the effect of IID. A stationary observer is presented pure tones of sound to one side. A difference in intensity occurs at the two ears, as one ear is shadowed by the head. The shadow is a function of frequency and a significant difference in loudness is perceived by the two ears. The figure indicates that at very low frequencies there is no difference and no impact from the shadow of the head. However, at frequencies above 5000 Hz a difference in loudness between the two ears is as great as 30 db. With complex sounds (e.g. speech, music, broadband sound) there will be not only this difference in loudness/intensity but also a change in the sound spectrum as high frequency components are shown to be lost to the ear on the far side of the head.



DIFFERENCE IN LOUDNESS-LEVELS AT THE TWO EARS WHEN PURE TONES OF VARIOUS FREQUENCIES COME DIRECTLY FROM THE SIDE. THE CURVE ILLUSTRATES HOW SOUND-SHADOW OF THE HEAD CHANGES INTENSITY AT VARIOUS FREQUENCIES. (SOURCE: HEARING ITS PSYCHOLOGY AND PHYSIOLOGY, AMERICAN INSTITUTE OF PHYSICS)

Figure 3

The concept of ITD can be explained in terms of sound waves traveling to your ears. The crest of each sound wave will reach the nearer ear before it reaches the ear on the far side of the head as depicted in Figure 4. A subject listening for the sound waves will tend to place the sound source toward the side of the first wave crest to arrive at the ear.

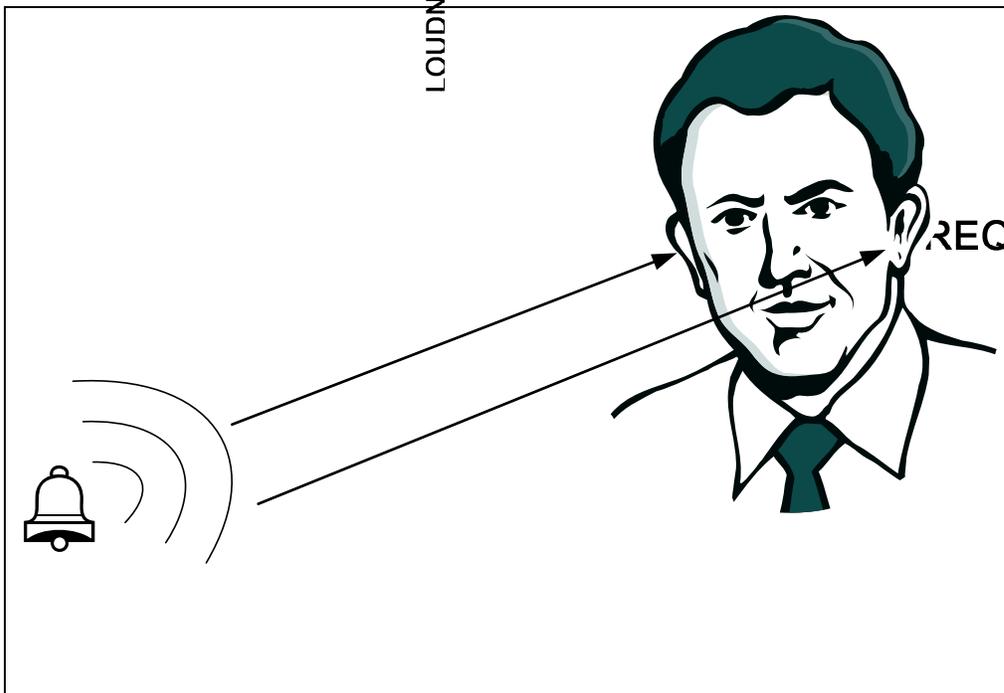
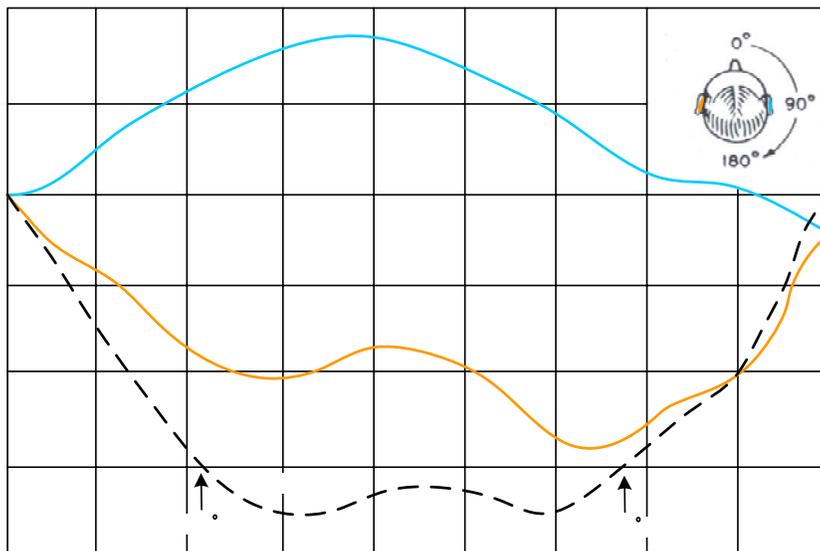


Figure 4

Withington⁹ and other sources^{12,13} note that intensity and timing differences can result in errors in localization and ambiguity and confusion for the listener when narrow band or single frequencies sounds are used. However, with broadband sources and sound durations that are long enough to allow listeners to move their heads, confusions of this sort almost never occur.¹³

The external ear or pinna is key to the third binaural cue known as the head-related transfer function (HRTF). The shape of the ear attenuates some frequencies and amplifies others, filtering the sound field as depicted in Figure 5. The HRTF changes depending on sound source location, providing an additional localization cue is particularly important to determining if the sound source is in front of or behind us. HRTF operates over a range of frequencies, but seems to be most effective in the 5,000 Hz to 10,000 Hz range. Combined with the listener's head motion, HRTF provides an independent localization method that complements and reinforces ITD and IID capabilities.



INTERAURAL DIFFERENCE - FRONT-TO-

4

Figure 5

While the binaural cues discussed above provide complimentary and redundant means for locating sound there is a fourth psychoacoustic phenomenon that assures that too many sound waves resulting from highly reverberant spaces do not cause confusion. This is attributable to the "precedence effect" of human hearing. The ear is capable of discerning and fixating on the first sound received (line-of-sight direct signal) and disregarding later signals (reflected sound). The acoustical signal arriving first at the ears

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suppresses the ability to hear other signals (including reverberation) that arrive up to about 40 milliseconds after the initial signal. A pulsing broadband directional signal makes good use of the precedence effect and can compensate for less than optimum listening conditions. Even in highly reverberant spaces, in which every surface was sound reflective, this author has noted that test subjects have had no problem determining the location of directional sounders.

Compatibility with Traditional Fire Alarm Notification Appliances

Directional sounders are envisioned as an additional evacuation aid to be used with, not as a replacement for, traditional notification appliances (bells, horns and speakers). Hence, during the period that people are exiting or relocating, there will be two dominant alarm system sound sources, both of which should be audible.

Figure 6 compares the spectrum of a typical fire alarm signal at a high setting with the spectrum of the directional sounder at a lower power setting. Note that while the typical alarm signal clearly dominates at 3000 Hz and to a lesser extent at upper harmonics, the broadband directional signal of the directional sounder is 20-30 dB louder than the fire alarm over most of the range. And although the fire alarm may have an overall A-weighted sound level 20 dBA or more higher than the overall A-weighted sound level of the directional signal, both alarms are audible. The reason that the directional signal does not actually have to be higher in overall sound pressure level than the traditional alarm signal is because the traditional alarm will only mask a narrow range of frequencies near the traditional alarm's dominant pure tones.

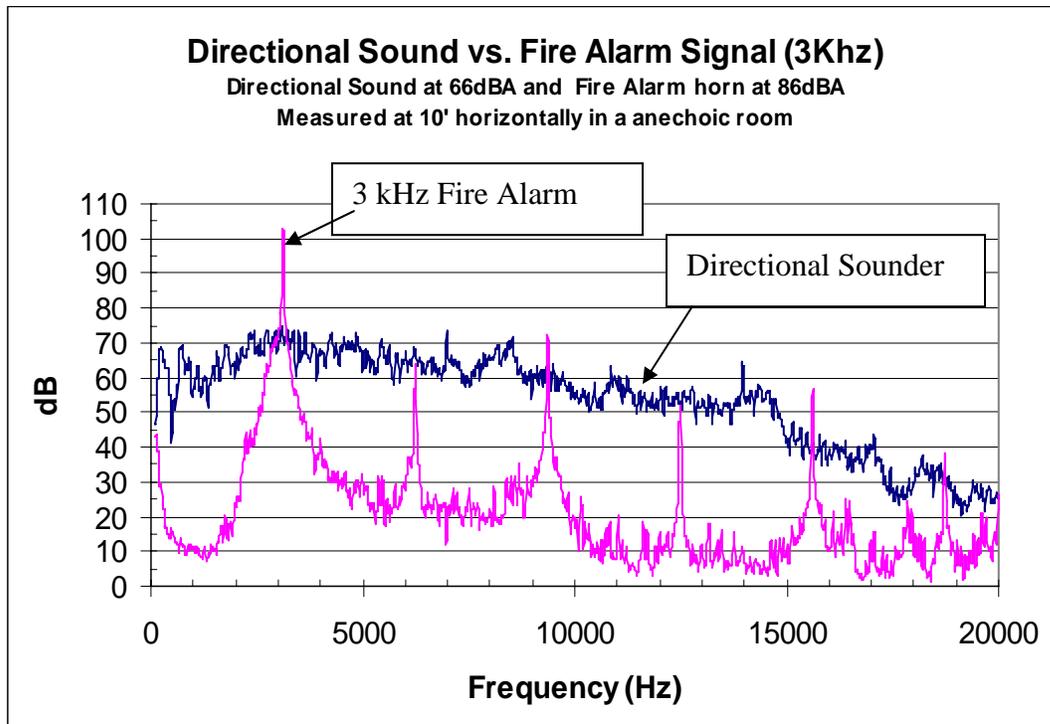


Figure 6, (Source: *System Sensor ExitPoint Directional Sound Application Guide*, Nov.2004)

Compatibility with Voice Evacuation Systems

Where directional sounders and voice evacuation systems employing speakers are utilized within the same occupancy the directional sounders can reduce the speech intelligibility of the voice speakers. In general, this effect is observed only when voice speakers are in close proximity to the directional sounders. Where simultaneous operation of the voice evacuation speakers and the directional sounders is to be implemented System Sensor offers guidance in their "*ExitPoint Directional Sound, Application Guide*" that will help to reduce the effects of the directional sounders on the intelligibility of voice speakers.

Influence on Human Behavior

The psychoacoustic response to directional sounders has been shown in numerous exercises and research studies with human subjects to lessen the time required for evacuation and to effectively assist occupants searching for egress routes and exits. A summary of several scenarios is presented in Table 1. While these exercises were conducted primarily on passenger ships and ferries,^{14,15,16,17,18} the results are broadly applicable to evacuation and relocation scenarios in buildings.

The various trials involved numerous scenarios such as evacuations with and without directional sound, evacuations with low visibility conditions created by use of theatrical smoke, and a variety of room and complex corridor arrangements. In smoke-filled scenarios with little or no visibility of exit signs, directional sound demonstrated its benefit to provide cues that significantly reduced the time for subjects to find the nearest exit and to find the exits without retracing their steps. In several cases directional sound was compared to the low location lighting (e.g. photoluminescent technology).

The egress behavior of subjects in normal visibility did not show the same extent of improvement in egress times, but subjects indicated the sound cue as a confirming aid in finding the exit. A more dramatic result was evident in evacuation trials when subjects received a briefing on the meaning of the directional sound. In these trials with briefings, the subjects consistently performed better at finding the closest exit and exhibited faster exit times.

Table 1 - Summaries of Human Subject Tests with Directional Sound

| | TEST STUDY & SCENARIO (Date of work) | VISIBILITY CONDITION | EXIT SIGNAGE STATUS / LIGHTING CONDITIONS | STATUS OF SOUNDERS (a.k.a. BEACONS) | SUMMARY OF RESULTS & COMMENTS |
|----|--|--|---|---|---|
| 1 | January 2000 tests on a ferry in dry dock. Subjects led, by two different routes, to two cabins in the center corridor of an accommodation section comprising three parallel corridors. Subjects told there would be one safe route through smoke filled corridors. (2000) | Smoke filled | Normal lighting remained on during tests. | Beacons not used | Subjects let out of cabins at 5 sec. intervals. About half went each way - left and right. Those who turned left found blind alley and blocked exit and had to retrace steps. Those who turned right reached a T-junction and had to choose left or right. Again, about half went each way of which those who went right found a blocked exit. |
| 2 | January 2000 tests on a ferry in dry dock. Subjects led, by two different routes, to two cabins in the center corridor of an accommodation section comprising three parallel corridors. Subjects told there would be one safe route through smoke filled corridors. (2000) | Smoke filled | Normal lighting remained on during tests. | Beacons activated, locations not reported. | Subjects let out of cabins at 5 sec. intervals. About half went each way - left and right. All subjects turned immediately right and then immediately left at the T-junction and were out in about 1/3 of the time it had taken the group before WITHOUT beacons. No one went the wrong way. |
| 3 | University of Cranfield and Greenwich in conjunction with an aircraft manufacturer and airline. The trials were conducted in a two aisle wide body aircraft in the coach section. The conditions of each trial were as follows: 1) no cabin crew assistance and no directional noise; 2) cabin crew assistance and no directional noise; 3) no cabin crew assistance and directional noise; 4) cabin crew assistance and directional noise. (2000-Dec) | Smoke began to fill cabin after a PA announcement of a "problem" | Emergency exit lighting activated approximately 5 min. after smoke | Beacons activated in 2 of the 4 trials | The participants and the cabin crew completed questionnaires following each trial and 90% of the participants indicated the sound had aided them to a safe exit. All of the crew members indicated the directional sound had not interfered with their evacuation procedures. The data showed an improvement in door usage with directional sound. It was noted that the sound beacons provide the ability to direct from forward area to the correct rear exits which the cabin crew alone was unable to do. |
| 4 | University of Strathclyde - evacuation trials were conducted onboard the ro-ro ferry, <i>Ile of Arran</i> in the crew accommodation area. Trials were varied to compare "directional sound" with existing evacuation guidance systems, such as low location lighting. (2001-June) | Smoke of 3% density | Low location lighting (LLL) | Beacons were either on or off in tests | In these four trials with all three exits available, the exit times were relatively short and the positive effect of the beacons was limited, resulting in a reduction of 9-17 % |
| 5 | University of Strathclyde - evacuation trials were conducted onboard the ro-ro ferry, <i>Ile of Arran</i> in the crew accommodation area. Trials were varied to compare "directional sound" with existing evacuation guidance systems, such as low location lighting. (2001-June) | Smoke of 3% density | Low location lighting (LLL) was on in 3 trials and off in three trials | Beacons were on in 4 trials and off in 2 trials | Two of the six trials did not use beacons and the 18 person travel times were 286 sec without LLL and 205 sec with LLL. In the trials with sound beacons the 18 person exit times were 109 sec (no LLL, no briefing), 102 sec. (with LLL, beacons, briefing), 100 sec. (with LLL, beacon) and 92 sec. (no LLL, beacon, briefing). Comparing the cases without sound to those with sound resulted in a reduction of exits times of 50% or more when sound was used. |
| 6 | University of Strathclyde - evacuation trials were conducted onboard the ro-ro ferry, <i>Calodonian Isles</i> in the forward restaurant and lounge areas. Trials were varied to compare "directional sound" with existing evacuation guidance systems, such as low location lighting. (2001-Sept.) | No smoke | LLL used at edges of corridors and stairs | Beacons on in 2 trials | In these tests <u>without</u> smoke subjects chose the closest exit as follows: 55 % (no sound, no briefing), 45% (with beacon) and 90% (with beacon & briefing). Also, 92% of subjects said that the beacons led them to an available exit, however, they indicated the exit signs were the most obvious help, and the sound was a confirmative aid. Regarding the presence of multiple beacons, 84% indicated they were aware of more than one beacon, and 88% chose to move towards the loudest one. |
| 7 | University of Strathclyde - evacuation trials were conducted onboard the ro-ro ferry, <i>Calodonian Isles</i> in the forward restaurant and lounge areas. Trials were varied to compare "directional sound" with existing evacuation guidance systems, such as low location lighting. (2001-Sept.) | Smoke of 3% density | LLL used at edges of corridors and stairs | Beacons on in 2 trials | In these tests <u>with</u> smoke subjects chose the closest exit as follows: 30 % (no sound, no briefing), 100% (with beacon) and 95% (with beacon & briefing). These smoke filled tests show many more subjects finding the nearest exit with the use of the sound beacons. Also, 85% of subjects said that they would rather rely on sound beacons than LLL. |
| 8 | University of Strathclyde - evacuation trials were conducted onboard the ro-ro ferry, <i>Calodonian Isles</i> in the after section of the ferry. Trials were varied to compare "directional sound" with existing evacuation guidance systems, such as low location lighting. (2001-Sept.) | 2 trials without smoke and 2 trials with smoke | Visual exit signs indicated exit direction was up, however, correct direction was to go down. Exit marked by LLL. | Beacon located at exit stair using "down sweep" sound | In these 4 trials the smoke and no smoke evacuation times are comparable since in clear conditions the exit was not clearly e. exit marked as "Crew Only". When directional beacons were used the decision to use that exit was reinforced. Once through the "crew only" exit subjects had to decide to descend or climb the stairway free of smoke. With no beacon all subjects chose to ascend, as instructed by existing exit signs. When the sound beacon was used all subjects heard the "down sweep" and descended on the stairs. |
| 9 | University of Leeds - Cruise Ships DSE Tests, Open public space 9 deck atrium, October 2002. Initially, subjects asked to identify exits from where they stood; after a few minutes sounders were activated and subjects asked to find their way to an exit. (2002-Oct.) | Smoke filled, visibility 1-2 meters | Lighted exit signs | Sounders set to 92-98 dB(A) located at 26 exits from 7 decks; 20 of the sounders located on lowest three levels | Most subjects commented they could not see an exit from their starting position, and none could see an exit sign. Several subjects commented that they were unsure of which sounder was closest, however after moving a short distance they were immediately able to tell the difference between sounders and locate the nearest exit by following the nearest sound. There were mixed reactions to the General alarm system - some had no problem, others could only just hear the alarm and others did not notice it at all. |
| 10 | University of Leeds - Cruise Ships DSE Tests, Evacuation of complex cabin accommodation space on a large passenger ship. (2002-Oct.) | Smoke filled corridors, visibility 0.5 -1.0 meters | Low location lighting (LLL) | Not active | 5 people (15%) could not see the LLL. 6 people (18%) who did see the LLL felt the LLL did not provide assistance to an available exit. 25 people (78%) crouched or went down on hands and knees. Average exit time 135.7 seconds. Average actual route distance - 24 meters. |
| 11 | University of Leeds - Cruise Ships DSE Tests, Evacuation of complex cabin accommodation space on a large passenger ship. (2002-Oct.) | Smoke filled corridors, visibility 0.5 -1.0 meters | LLL shut off | Sounders on, number and locations unknown | All subjects could hear the sounders and all felt the sounders guided them to an available exit. 24 people (75%) heard 2 or more sounders on their journey and all chose to go to the loudest one. 11 subjects (34%) delayed their journey to understand the direction of the sound. 25 subjects (75%) heard the PA and GA alarms during the test. Average exit time 60.5 seconds. Average actual route distance - 21.7 meters. This test USING SOUNDERS allowed subjects to evacuate 55% faster than in the test using LLL. |

The benefits of directional sound are illustrated by several of the test studies; however, directional sound may not be of great utility in all occupancy types. For example, hospitals may not benefit significantly from directional sound due to the nature of the occupants, staffing and evacuation procedures. Consider for example that in a hospital evacuation training relies heavily on the action of staff and not patients and that a general evacuation is not a usual first choice procedure. In hospitals protect-in-place or patient relocation procedures implemented by staff would be expected first. Also, because of required fire drills

hospital staff is typically well acquainted with the locations of exits and refuge areas.

The several human subject studies conducted on ships and ferries demonstrates the benefits of directional sound in effectively providing useful cues that promote more efficient evacuation in conditions of limited visibility (as created using theatrical smoke.) The utility of directional sound in smoke filled or limited visibility conditions is apparent as a result of the work that has been done in simulated smoke filled conditions. The utility, however, is also a function of the likelihood of occupants encountering smoke filled conditions in the building environment. There is much documentation and statistics that support the effectiveness of automatic sprinklers as a life safety tool for public building occupants including those persons who may have a disability or mobility impairment.¹⁹ Full-scale fire tests have demonstrated that sprinklers are effective and that sprinklers will significantly limit the smoke toxicity and visibility hazard.²⁰ In the case of sprinklered buildings an emphasis on smoke filled or smoke obscured egress routes is far less a concern than for buildings without automatic sprinklers. Although the benefit of directional sound in sprinklered buildings is not supported by a view of fire considerations and fire related statistics, the benefits of directional sound deserves consideration in a broader view of emergency evacuation for emergencies of all types which includes fire, tornado, earthquake, hazmat incidents or other possible credible concerns.

Education and Training are Important Factors

Just as we have all learned at some time in our lives that red means “stop” and green means “go,” it will be necessary for people in buildings with directional sounders to learn what the signals mean and how to react to them. Although some research appears to show that people will intuitively react to directional sound, it should not be assumed that people will react in an intuitive manner. Research conducted with direction sounders, however, does show that training and education will increase the effectiveness of directional sound installations. Building managers, safety directors or others with responsibility for building emergency evacuation procedures should be aware of the importance of education and training where directional sounders are used.

Summary

The study of human behavior in evacuations reveals two phenomena that appear common in evacuations of buildings. First, is that occupants tend to exit a building by the route familiar to them, which may be the same route they used to enter a building. Second is the concept of “learned irrelevance” of exit signs, where people continually exposed to exit signage seldom consider the information it is intended to convey, i.e. the identification of alternative exits and exit access. In an emergency, occupants may fail to respond to signage pointing

to alternate means of egress, instead opting for the exits with which they are familiar.

There are other limitations to the way we identify the means to reach a point of safety in a building during a fire or other emergency that necessitates evacuation or relocation. Persons with visual disabilities will have difficulty with emergency information that relies on visual cues. The standard fire alarm signals that alert building occupants to an emergency event and communicate the need to evacuate usually are both audible and visual, but they give no clue as to which way to turn to reach an exit. Of course, at the time of a fire, when exit signs are most needed, it is possible for smoke to obscure exit signs and the location of exit doors.

Directional sound offers a means to address these limitations by providing an additional stimulus in the form of sound cues that draws attention to otherwise ignored egress routes and exit locations. The broadband sound pulses of directional sounders make use of our natural ability to localize sound sources. The resulting impact on human behavior is that directional sounders can be effective in reducing the time required for evacuation and assisting occupants searching for egress routes and exits. Given that adding directional sound to a buildings fire alarm system is estimated to be only a 4-8% additional cost, it is reasonable that the enhancement of directional sound is worth consideration for a variety of occupancies.

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- ¹⁷ University of Strathclyde, *Marine Trials Scenario 2 – Open Spaces & Stairs, Results Data and Statistical Analysis*.
- ¹⁸ Sub-Committee on Fire Protection, [Large Passenger Ship Safety, Results of Analysis Carried out by the University of Strathclyde](#), FP46/INF.9, 11-30-01.
- ¹⁹ J.H. Klote, H.E. Nelson, S. Deal, B.M. Levin, NISTIR 4770, *Staging Areas for Persons with Mobility Limitations*
- ²⁰ Madrzykowski D., NISTIR 4631, *The Reduction in Fire Hazard in Corridors and Areas Adjoining Corridors Provided by Sprinklers*