A paper presented by Prof. Withington at the XIVth Triennial Congress of the International Ergonomics Association & 44th Annual Meeting of the Human Factors and Ergonomics Society, San Diego – August 1st, 2000.

THE USE OF DIRECTIONAL SOUND TO IMPROVE THE SAFETY OF AUDITORY WARNINGS

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We all recognise the siren of an emergency vehicle, but none of us is able to tell which direction it is coming from. We can identify 'what but not where’. This is due to the narrowband nature of traditional sirens, which due to the paucity of frequencies utilised, make it impossible for the brain to compute the location of the approaching emergency vehicle. Trials of a new siren sound, which comprises broadband noise, have shown that road users react positively to the new sound, resulting in journey times reduced by up to 10%. The Localizer® is thus safer for road users and emergency service personnel.

The ability to locate accurately a point of light is something we all take for granted. Take any starry night, for example, and we can identify spatially numerous points of light. We can pinpoint a light source to within fractions of a degree. What we are less aware of is our ability to locate a sound source. Yet sound localization accuracy is to within five degrees, not as accurate as our visual equivalent but, nevertheless, still remarkable. Virtually all light sources can be localized and thus we are acutely aware of this ability. Unfortunately, very few sounds can be accurately pinpointed, leading to the misconception that we cannot tell easily where sound is coming from. The ability to pinpoint a sound source is a fundamental prerequisite for all animals' survival, humans included. It is a basic requirement for both predator detection and prey capture and, as such, is an ability that is common throughout the animal kingdom. So what makes a sound localizable, or in other words, directional? First, we have to examine how our brain interprets sound. We can hear a huge range of frequencies from approximately 20Hz to 20kHz. There are three cues that are utilised, and all have to be present, for sound to be localized. 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 which 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, and at higher frequencies the salient cue is the loudness/intensity difference between the sound at each ear. 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. For single frequencies these cues are, however, spatially ambiguous. The inherent ambiguity has been described as the 'cone of confusion" and this arises from the fact that for any given frequency there are numerous spatial positions that generate identical timing/intensity differences and 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 localise pure tones.

The final main piece of information processed by the brain regarding sound localization is called the head related transfer function (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 pinnae, the sound is modified so that some frequencies are attenuated and others are amplified. Although there are certain generalities in the way the sound is modified by the pinnae the HRTF of any 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 in summary, to locate the direction of a sound source, the larger the frequency content, to overcome the ambiguities inherent to single tone sounds, the better the accuracy. Knowing that we need a multi-frequency sound for localization, how can this be combined with our need to use sound as an alarm? There is a myriad of different uses for sound in alarms and in some cases the addition of a localizability component would be superfluous. However, there are other alarms in which the lack of localizability/directionality is potentially highly dangerous. Three examples of alarms in which the addition of directional sound has tremendous benefits are emergency vehicle sirens, man-down alarms used by fire-fighters and sound beacons used for evacuation of buildings, aircraft etc.

An everyday occurrence for the majority of drivers is the sound of an emergency vehicle siren, whether from an ambulance, police car or fire appliance. When the emergency siren is heard, drivers look all around, trying to determine from which direction the sounds are coming. The visual cue is required because the sound alone gives no clue as to which direction the vehicle is coming from. The driver is not able to take appropriate avoiding action until the emergency vehicle is seen, often too late to allow a clear path to be created for the emergency vehicle. This uncertainty regarding the direction of approach costs lives. Any improvement in the sound quality of the siren, which enables road users to take earlier evading action, would both reduce the journey time and enhance the safety for emergency vehicles attending emergencies and thus strengthen the service provided. It would also be safer for road users, pedestrians and drivers alike.

Difficulties in determining the direction from which emergency vehicle sirens are approaching are widely acknowledged. In fact, the emergency vehicle siren has been described as "an extremely limited audible warning device". A recent study in the Annals of Emergency Medicine has shown that an ambulance is most susceptible to collisions with other vehicles when crossing road junctions. This happens, primarily, because the drivers of the cars or trucks are unable to determine accurately the direction of the approaching ambulance. In one year, in the U.S.A. alone, 537 Juries and 62 deaths arose from accidents involving ambulances.

So why do they not work'? Simply, because the frequency content of the siren sounds is so poor. Typically emergency vehicle siren sounds are emitted over the frequency range 500Hz-1.8kHz, far too narrow a frequency range for localization. Laboratory and field trials of siren sounds in which a pulse of broadband sound was interspersed throughout traditional siren sounds showed conclusively significant improvements compared with existing siren sounds (e.g. wail and yelp). In laboratory tests, the new siren sound, called "The Localizer®" resulted in the correct identification of sound from in front/behind the listener 82% of the time compared with just 44% of the time with the old sirens (guessing would have resulted in 50% accuracy!). Data showed that with The Localizer emergency vehicle lane changes were reduced threefold, so making journeys smoother and faster. Instant recognition of the direction of the ambulance's approach increased by nearly 25%, which meant that other drivers co-operated more quickly and more effectively with the emergency vehicle's passage. Clearer, well-signalled manoeuvres by road users were more achievable and increased by 17%. Finally, journey times were reduced by up to 10%. This reduction in journey time was not due to the fact that the emergency vehicle was travelling faster and, often owing to the natural caution of driving with something new, their speed was actually less. It was due, rather, to the fact that road users reacting more quickly, and more appropriately, to the new siren, allowing a clearer path through the traffic for the emergency vehicle, made the journey easier.

It seems, therefore, that the two crucial requirements of a siren sound, to alert road users to the presence of an emergency vehicle and to inform the listeners of the direction of approach, can be met by utilising our scientific knowledge of the best types of sounds to fulfil these criteria, thus resulting in a more effective sound signal.

There are many other cases in which changes in the nature of the sound would enhance the efficacy of the application. For example, man-down alarms worn by fire fighters, are activated under conditions of extreme urgency. The sound emitted should not only alert colleagues of the stricken fire fighter, but should also provide useful information to aid their search for him or her. Existing man-down alarms use single-tone, relatively high frequency signals of approximately 3kHz. These sounds are not ideal in terms of perceived urgency and, more importantly, they are impossible to localize. Localization errors are, in fact, greatest for sounds around 3kHz. Field trials with fire fighters of a new man-down alarm in which the traditional, familiar, sound was retained but also had pulses of broadband noise showed dramatic improvements of the new sound compared with just using the existing single tone alarm. The Localizer man-down alarm was located up to 4.6 times faster than the traditional sounding alarm; an improvement that could mean the difference between life and death for a stricken fire fighter.

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, which 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 if 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 beginning to organise 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. 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 shown repeatedly that one of the most natural instincts in the event of a fire is that people evacuate a building using the route by which it was 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!

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

Given that vision is our primary mode of perceiving our environment, it is not surprising to find that the majority of emergency egress aids, such as emergency lighting, signage, colour coding and photo luminescent guidance strips are solely visual based. How effective are such aids when the part of the building you are in is completely occluded by smoke, or indeed if you are among the millions of people who are registered visually impaired? It is clear that this reliance upon visual means just isn't good enough in modern building 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.

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 impossible to locate because they emit only a narrow frequency range of sound.

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

A second series of tests took place in a deserted junior school owned by the University of Leeds. A complex route was devised which would test the egress beacons to their fullest, including many directional decision making points and also staircases. Subjects in these trials included sighted, visually impaired adults and children having completely filled the school with artificial smoke, each Subject was taken to the starting point of the experiment, on a first floor location, which could be accessed directly via an external emergency escape staircase. By doing this, subjects had absolutely no idea of the route that they were about to go through. In addition, they had no idea of the intended meaning of any of the beacons as will be described subsequently. Once ready, all beacons and the building's existing fire alarm were activated and each subject, or group of subjects entered into the smoke. Essentially, the whole route was marked by only four evacuation beacons placed at strategic points (mainly above fire doors) on the way. At one point en route, there was a small flight of stairs which led upwards to a mid-level in the building, and a beacon was designed, which as well as having rapidly pulsing broadband noise, also included an upwardly sweeping melodic complex which denoted 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 regard to faster events signalling 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 denoting "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 reduced close to total travel times that would have been expected under ideal visual conditions with prior knowledge of the building.

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, they removed the need for having prior experience with the environment, reduced hesitancy and totally eliminated way finding errors. Overall evacuation time was substantially reduced (by more than two thirds in many cases). Although not part of the trials, these beacons also have the added advantage of alerting building users to exits that would otherwise have been missed (if for example they are out of the direct line of sight), helping to reduce the obvious problem of overcrowding at main entrances and stairwells. The use of broadband noise provides a further dimension to identifying egress routes in that it is totally language independent, providing exit marking for all nationalities.