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The Quest for Better Ambulance Sirens

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An every-day occurrence for the majority of drivers is the sound of an emergency vehicle siren, whether from an ambulance, police car or fire tender. 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 make appropriate avoiding action until the emergency vehicle is seen, which is 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, will both reduce the journey time and enhance the safety for emergency vehicles attending emergencies and thus, strengthen the service provided. It will also be safer for road users, pedestrians and drivers alike.

Difficulties in determining the direction from which emergency vehicle sirens are widely acknowledged. A recent study in the *Annals of Emergency Medicine* has show 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 US alone, 537 injuries and 62 deaths arose from accidents involving ambulances (Hunt et al 1995).

The psychoacoustic requirements for a sound to be localized with any degree of accuracy are not incorporated into the sound patterns of existing sirens. Indeed, it is recognised that the emergency vehicle siren is "an extremely limited auditory warning device" (De Lorenzo and Eilers, 1991). Auditory localization, i.e. our ability to pinpoint the direction of a sound source, is achieved by extremely complex processing in the brain. The auditory cues used for sound localization depend predominantly on the fact that we have two ears. A sound to the right, for example, will be louder in the right ear than the left, i.e. there are intensity differences between the two ears. Additionally, a sound from the right arrives at the right ear before the left, that is referred to as a timing difference. The external ear flap, the pinna, also makes important differences to the quality of sound. An individual's pinnae are almost as unique as finger prints and are essential for sound localization. The problem of localization arises from the fact that for any given frequency there is a large range of spatial locations which provide the same auditory cues. Therefore, pure tones, or sounds containing only a few frequencies (which typify existing sirens) are spatially ambiguous and are consequently very poorly localized by our brains. Accurate sound localization is, however, perfectly possible given the right sound in the first instance. We are capable of determining the position of a sound source to an accuracy of 5°. We hear sounds over huge frequency range of about 20 Hz to 20,000 Hz. For a sound to be localizable it must contain as much of this frequency range as possible. Existing sirens operate only over a tiny portion of our hearing range, just 500- 1,800 Hz. It is, therefore, hardly surprising that they cause such difficulty when trying to pinpoint the direction of approach.

In addition to being localizable, ambulance sirens should also be "alerting", in other words, attract the listener's attention. Although it is generally assumed that existing sirens are alerting, this may, in part, be due to familiarity and learned association of emergency vehicles with the existing sounds. The scientific literature on what makes a sound alerting (e.g. Patterson, 1982), indicates that existing siren patterns don't even possess this characteristic in an optimum form.

As a result of obtaining a Department of Trade and Industry SMART award (Small Firms Merit Award for Research and Technology), Sound Alert Ltd. undertook the quest to improve our emergency vehicle sirens. The first SMART award ran from September 1994 - September 1995 and was used to finance a feasibility study in which the performance of existing siren sounds was compared to scientifically designed sounds, with respect to localization characteristics. Sound Alert Ltd. has recently been awarded SMART 2. The purpose of the SMART 2 funding is to extend the research further by designing and testing prototype new sirens.

To undertake the feasibility study encompassed by the SMART 1 award sound localization accuracy of sounds was tested using a state-of-the-art driving simulator based in the Department of Psychology at the University of Leeds. The engine and road noise of the car were generated by a Roland 5760 digital sampler controlled by the simulator computer (Silicon Graphics reality engine). Approximately 200 participants (age range 19 to 57 years) were tested. They all had previous driving experience. A hearing test, in the form of an audiogram, which tested the ability of each participant to hear a range of frequencies, was performed on most participants. Eight loudspeakers were positioned at 45° intervals around the car's azimuthal plane. The speakers are not visible to the participants, and the sound from each speaker is intensity and spectrally matched at a position which marked the driver's head within the car. Matching each speaker in the way described resulted in the only variable each time the sound was played was that of direction. A response panel was mounted by the steering wheel in the car. There were 16 positions marked on the panel which represented the horizontal plane around the car. This allowed greater accuracy in determining the errors made by the participants than just having 8 response buttons that corresponded directly with the number of speakers. On hearing a siren sound noise, participant drivers pressed the response button that they judged as equating to the location from which the sound originated. The sound source location was varied randomly, with the constraint that in each session all 8 speaker positions were activated twice. The participants began trials after a period of familiarisation with the car (a 10-minute `drive' along a pre-set rural route). During the trials the participants were asked to maintain a speed of 40 m.p.h. which the experimenter monitored continuously.

Four existing sirens were tested. These were the "hilo" siren characterised by a two-tone sound (670-1100 Hz, 55 cycles/min); the "Pulsar", a pulsating sound (500-1800 Hz, 700 cycles/min); the "wail", a continuous sound rising and falling (500-1800 Hz, 11 cycles/min) and the "yelp", a continuous and fast warbling sound (500-1800 Hz, 55 cycles/min). In each trial the same siren sound was used. The siren sound was delivered at/around road junctions on the test track. In addition to the existing sirens a range of new sound patterns was tested. The new sound patterns contained alerting and a localizable phases which were combined to produce a composite signal.

Data have now been gathered showing conclusively the poor localization characteristics of existing sirens, though some are better than others; for example, the traditional "hilo" siren is significantly worse for localization than the "yelp". Nevertheless, even the best of current sirens was associated with exceedingly poor front/back accuracy: participants had difficulty identifying whether the sound emanated from the front or rear of the car, to the extent that they were wrong more often than not (See Figure 1). It is worth noting that if participants just guessed front or back, in theory they would have been correct 50% of the time. In contrast, with the newly- created sound-patterns from Sound Alert Ltd., the corresponding judgements were made correctly most of the time (Figure 1).

Left/right judgements are not as difficult as front/back decisions, and so measuring accuracy is more appropriate than right/wrong. The response of the participant to left and right sounds was scored as accurate if they identified the location of the sound ± 22.5°. Participants performed reasonably well with the existing sirens in left/right precision, but they performed appreciably better with the new sounds (Figure 2). The new

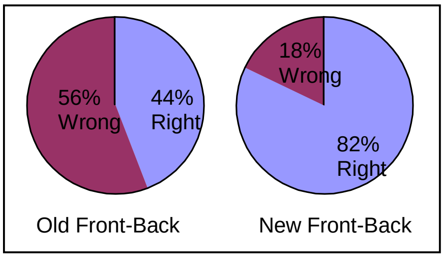

Figure 1: Pie charts showing the % of particular responses which judged correctly whether the sound was played from the front or rear of the car, using the old siren (left) and using the new sound patterns (right).

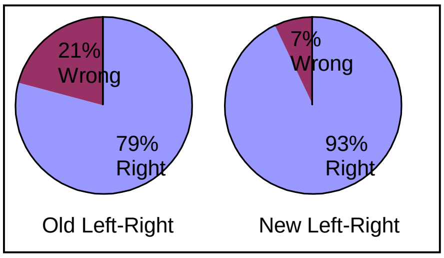

Figure 2: Pie charts showing the % of particular responses that were accurate to $\pm 22.5^o$ of sound coming from the left or right of the car, using the old siren (left) and using the new siren sounds (right).

sounds consist of rapid frequency sweeps, and associated with each train of frequency sweeps is a burst of broadband noise. The aggregate pattern optimises both the alerting and localizing features of a sound configuration. There is a range of sound patterns, covered by this description. Each sound has a different fundamental frequency (which changes perception of pitch) and thus we have a choice of sounds available for emergency services. (Sound Alert Ltd. has filed a patent to protect the new sound patterns.)

In addition to testing the localization characteristics of sounds, the "alerting" nature of old and new sirens was examined. This was done by giving the participants a questionnaire at the end of each trial and asking them to rate, on a 1 - 5 scale, how alerting they found each sound. As expected, all the existing siren sounds scored highly, with little to choose between the different types. It was, however, pleasing to discover that the new sound patterns scored equally as well, even through the participants were unfamiliar with them.

With the co-operation of emergency vehicle services (in particular, West Yorkshire Metropolitan Ambulance Service) we are now complimenting the data from the driving simulator, by road-testing the sounds on ambulances (financed in part by the SMART 2 award). We are monitoring pedestrians' and drivers' responses to both existing sirens and to our new siren-sounds. Through video apparatus mounted in the ambulance cab, we are filming road users' responses with the siren operating. Frame-by-frame, this analysis gives the detailed manoeuvres of vehicles, including avoidance measures. We can, thus, divide road users' responses into broad categories of helpful and unhelpful (even dangerous) manoeuvres from the viewpoint of the ambulance crew. More detailed analysis into specific types of responses is also possible which may be useful for detecting more subtle variations between responses to different sirens. Ambulance crews' impressions of the sounds are gauged through interview schedules.

To return to a general problem associated with emergency vehicles, road users on hearing a siren rarely know whether it is an ambulance, fire engine or police car. The type of avoidance action initiated by a road user is different in anticipation of, say, a police car or a fire tender, if only because they differ in size and manoeuvrability. Through discussions with all the emergency services, Sound Alert Ltd. takes the view that road users should be able to identify the different emergency services by the sounds they use on their vehicles. Ideally, the emergency services should have distinct siren sounds allowing one service to be distinguished from another. Finally, if ambulances are fitted with sirens that produce optimally alerting and localizable sounds, they can be made safer, both for their occupants and for other road users, and they will be able to travel more swiftly to and from emergencies as necessary.

References

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