# A Field Investigation of Conditions Governing the Use of Auditory Warning Signals in Industry

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A framework has been proposed for systematic analysis of possible mismatches between auditory demands and capacities in the workplace [1]. At present, very little information is available concerning the conditions governing perception of auditory warning signals (AWS) in industry. In a preliminary study conducted in a large steel mill [1], it was found that signals were too faint with respect to the prevailing background noise in more than one case out of three, and too loud in one case out six. This finding confirmed the need for systematic data collection on the conditions governing the use of auditory warning signals in industry. The present study was undertaken as part of a demonstration project, initiated by the Institut de recherche en santé et sécurité du travail (IRSST). The aim was to characterize the effectiveness of defective production signals and danger signals in different industrial settings.

## Method

### Plants visited

A total of 8 plants participated in this study. The bipartite occupational health and safety committee was first contacted for consent to participate in the study. The plants included the following industrial sectors: metal products, wires (n=2), auto parts, domestic appliances, printing and steel structures. They employed from 70 to over 400 workers.

### Equipment and procedure

In each plant, a representative of the health and safety committee organized the visit. AWS were identified in each department. They were recorded under the quietest possible conditions. Then, a representative 10-s sample of the noise surrounding workers targeted by the signal was recorded. Measurement equipment included a BK-2231 sound level meter with BK4155 free-field microphone and a Sony MZ-1 magneto-optic digital recorder. The samples were later assessed using a BK-2123 analyzer. Horns operated on vehicles were recorded at a distance of 4 meters directly in front or behind.

### Data treatment

The data were analyzed using DETECTSOUND™ [2-3]. Masked thresholds for AWS were determined in relation to prevailing background noise, with reference to the median normal hearing sensitivity of 55-year old males. Recognition threshold, based on findings from a field study [3], were set at +12 above estimated masked thresholds. The appropriate frequencies for signal design ranged from 0.25 to 3 kHz. A minimum of 4 recognizable spectral components was required for a signal to be judged as adequate [4]. An absolute limit of 105 dB SPL was also included in the assessment criteria, given that AWS should not induce temporary or permanent threshold shift.

## Results

In all 8 plants visited, there was no one explicitly in charge of AWS. No register for such signals had been put together, nor was there any maintenance schedule.

In fact, when a signal source proved to be defective, maintenance electricians were asked to take charge of repairs and adjustments. In most places visited, AWS were identified by the safety personnel while we were conducting data collection in their plant. In other words, AWS were not considered as a safety issue even if an explicit health and safety policy was in effect in all 8 participating plants.

### Fire alarmss

In most of the plant visited, it was not possible to assess one particular type of signal, namely, fire alarms, because it would have required that production be stopped for a significant period of time. It was nevertheless noteworthy that no routine testing of such signals existed in most places. In one plant, evacuation exercises were conducted yearly, but workers were directly alerted by foremen during such exercises. This procedure did not allow the plant to test the effectiveness of the alarms in all work areas. When assessing such alarms, it was found that they were too faint in over 50% of the work areas. In another plant, the fire alarm was the same signal as the one announcing coffee breaks, except that it was operated in a continous mode. That particular signal was inaudible to all workers who were engaged in the most common high-noise activities in this structural steel plant, i.e., gouging, grinding and chiselling.

### Stationary signals

In all the plants visited, process AWS were being used. The more automated the process, the more frequent the use of AWS. Typically, signal sources were installed by equipment manufacturers and had not been adjusted to the sound environment in which the machinery was installed and operated. Horns activated when operating moving cranes constituted the most common type of danger signal used. Systematic analysis of stationary signals, including fire alarms, showed that they were too faint to be recognized over the background noise in half (50%) of the 124 assessed conditions under which they were used (Figure 1). No single component of these signals met the recognition threshold for normal listeners. Furthermore, less than 20% of the stationary signals actually met the ergonomic design criterion of 4 recognizable spectral components.

In most plants, signal audibility was to some extent inversely related to the level of background noise. However, it was striking to find that, in the most quiet plant visited (with maximum backround noise levels below 85 dBA in all but one work area), less than 15% of the stationary signals were adequate. This was due mainly to the fact that very high frequency components ($\geq 3.15$ kHz) were used for process signals and moving crane signals. In such cases, the signals were actually often too loud; they were said to be very annoying by workers who took part in the data collection.

In the more noisy work environments visited, AWS effectiveness was further assessed with account taken for high frequency noise-induced hearing loss combined with effective individual protection. In such cases, the signal design window was restricted to frequencies below 2 kHz. But this constraint was not routinely taken into account in the workplaces surveyed.
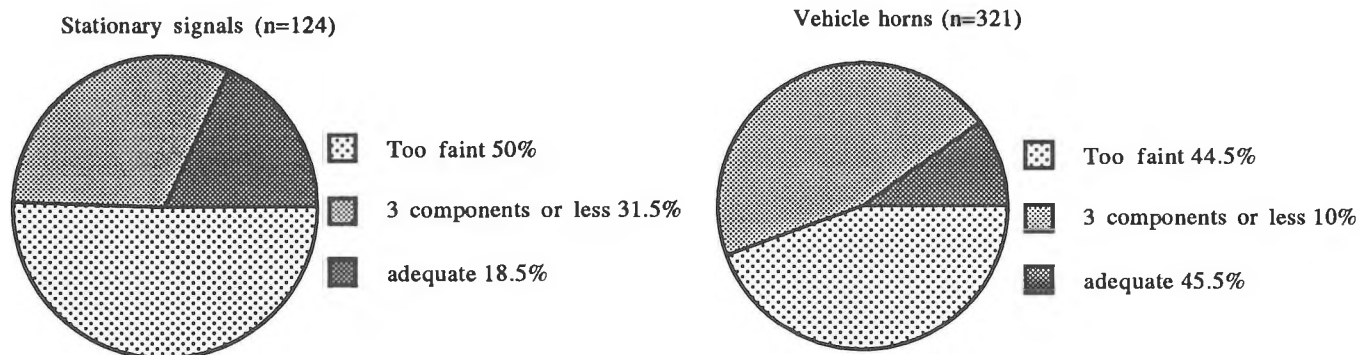
Stationary signals (n=124)

Vehicle horns (n=321)



Too faint 50%

3 components or less 31.5%

adequate 18.5%

Too faint 44.5%

3 components or less 10%

adequate 45.5%

Figure 1. Assessment of sound warning signals under a specified number of conditionsgoverning their use in 8 factories. Adequate signal level was defined as 4 spectral components that reached at least 12 dB over the masked threshold for unprotected normal male listeners.

Lift truck horns

Lift trucks were quite extensively used in all plants visited. In most the lift truck, operators had de-actived or muffled the backup signal because it was felt to be too annoying. It is interesting to note that these vehicles operate in reverse gear for a significant lenght if not most of the time. The backup signal is thus on for long periods and loses its effectiveness as warning for people who work in areas of lift truck circulation. Another striking feature of the backup signals is that they consisted of one or two pure tones whose frequencies fell in a range of 1 to 3 kHz. The use of pure tones makes the signal highly sensitive to geometric interferences. The frequencies chosen happen to fall in a range in which human auditory localization is poorest for pure tones. The above observations call for a serious re-examination of the usefulness and effectiveness of backup signals.

As for the horns, a very wide variation of sound power could be observed. In some plants, there was a correlation between the mechanical power of the truck and the acoustic power of the horn, even though the various vehicles circulated in the same sound environement. In no instance was the horn specifically adjusted to the background noise in the work area. As a result, horns were found to be adequate in less than 50% of the 321 assessed conditions under which they are used, as indicated in Figure 1. Horns were definitely too faint in nearly 45% of the conditions. In one particular plant, the production process relied heavily on the use of lift trucks. Ten different models of trucks were used. Among them, the maximum third-octave band output level at 4 meters was lower than 80 dB SPL for 2 trucks; it ranged between 80 and 86 for a group of 4 trucks, and between 90 and 97 dB SPL for another group of 4. Accordingly, those with the faintest horns were found to be adequate for only the most quiet area of the plant, shipping and warehouse. They nevertheless circulated in other much noisier areas. Furthermore, in three of the most noisy production areas, the most powerful horn was too faint to be recognized over the background noise. Overall, lift truck horns had recognizable spectral components in less than 35% of the conditions under which they were uses in the plant. This example illustrates the fact that horns from lift trucks are not considered to be an important safety device. It also points to the need for adjustable horns that can meet the requirements imposed by different sound environments in a given plant.

Discussion

The above findings suggest that AWS are not being considered as a safety issue in industry. The lack of a register,

of assessment and maintenance routine, and the lack of signal adjustment to listening conditions, point to a lack of awareness of the auditory demands in the industrial work environment. This situation might reflect what was pointed out in an analysis of the prevailing paradigm concerning hearing in industry [4-5], namely, that there is little if anything to be heard when the overriding concern is to protect one's hearing against high noise levels.

Observations reported above call for a systematic review of current industrial hygiene practice regarding acoustic signalling. If indeed AWS are used to transmit important information about production processes and danger situations, they need to be systematically assessed, and redesigned or replaced when minimal perceptibility criteria are not met. This implies having access to some kind of repertory of signal sources with proper specifications on frequency components and sound power levels. These observations also raise the need for adjustable sound sources, especially for vehicle horns, in order for such devices to meet the different requirements imposed by the various sound environments that typically characterize industrial settings. A simplified model of AWS propagation would also help safety personnel to specify the sound power of devices such as fire alarms that must cover large work areas under variable noise and propagation conditions.

References

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