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Effect of personal safety equipment (hearing protection and helmet) on the localization of reverse alarms

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ABSTRACT

While reverse alarms are mandatory on most heavy vehicles, accidents still occur during the course of reversing manoeuvers. Recent studies have addressed the limitations of traditional reverse alarms ("beep-beep") compared to broadband alarms ("pschtt-pschtt"). In workplaces where reverse alarms are used, workers are often required to use personal safety equipment such as hearing protectors and helmets. The current study explored the effect of such equipment on the ability to localize both types of alarms in 3 groups of individuals with normal hearing using earmuffs, ear plugs or double protection, with and without concomitant use of a helmet. Results revealed a significant effect of alarm type (with better results for the broadband alarm) and type of hearing protection (with a marked degradation in performance using double protection), while safety helmet use did not seem to impact localization to a great extent. These findings could help raise workplace awareness as to the potential impact of safety equipment on sound localization and identify other viable alternatives (e.g. traffic management plan) when reverse manoeuvers are performed in the vicinity of workers.

INTRODUCTION

Despite the mandatory use of reverse alarms on most heavy vehicles, accidents, often deadly in nature, still occur yearly [1-2] in a variety of workplaces (i.e. construction, transport, mines, municipalities). Previous studies have demonstrated the limited efficiency of traditional (tonal "beep beep") alarms compared to broadband ("pschtt-pschtt") alarms in ensuring worker safety [3].

Workers in noisy environments are often required to use personal protective equipment, including hearing protection devices (HPDs) and safety helmets. While conventional passive HPDs are the most commonly used type of hearing protection, they are generally detrimental to sound localization [4-6], mainly by increasing the number of errors in the front/back dimension. Further, earmuffs are generally more disruptive to sound localization than earplugs [7-8].

Few studies have specifically addressed the effect of HPDs on the sound localization of reverse alarms. Alali and Casali [9] looked at the effect of 7 HPDs compared to unprotected performance when head movements were allowed. Only performance with diotic earmuffs was found to be significantly lower than all other listening conditions, including unprotected, a finding attributed to the loss of binaural cues resulting from the device's single microphone feeding to both ear cups. Localization was overall better in the left/right plane compared to the front/rear plane and results showed some advantages of a modified alarm over a conventional alarm. In Vaillancourt et al. [3], subjects were asked to remain still and identify the perceived location of a traditional tonal alarm and a broadband alarm. Compared to unprotected performance, passive earplugs did not significantly impact sound localization; however, passive earmuffs increased the number of front/back confusions for both alarm types and the number of left/right confusions for the tonal alarm.

Despite their frequent use in workplaces where heavy vehicles are in operation, the effect of safety helmets on sound localization remains relatively unexplored. Finally, workers seldom focus all their attention on the perception, identification, recognition and localization of reverse alarms and must concurrently perform multiple work tasks while maintaining high vigilance as to potential dangers such as reversing vehicles. While Merat and Groeger [10] found an effect of cognitive tasks on the ability to localize 100-msec tonal bursts, Nélisse et al. [11] found no effect of a primary task performed on a computer tablet on the sound localization of two reverse alarms in individuals with normal hearing not wearing hearing protection.

The main objective of the current study is to follow up on Nélisse et al. [11] and explore the effect of personal safety equipment (passive hearing protection and safety helmet) on the sound localization of reverse alarms while performing a primary task.

METHODS

A total of 72 (38 M; 34 F) young adults with normal hearing between the ages of 18 and 36 years old (average = 24.7; s.d. = 4.0) were divided into three groups of 24: 1) passive earplugs (EAR Ultrafit; NRR = 25 dB), 2) passive earmuffs (PELTOR Optime 95; NRR = 21 dB), and 3) double protection.

Two reverse alarms (tonal and broadband) were investigated in this study. The tonal alarm consists mainly of a 1264 Hz pure tone and much weaker higher frequency harmonics, with each alarm cycle lasting 990 ms (a 500-ms "beep" and a 490-ms pause). The broadband alarm's acoustic energy is spread over a larger spectrum, mainly from 700 Hz to 4000 Hz, and lasts 770 ms per cycle (400-ms "pschtt" and 370-ms pause).

Keeping their feet fixed to markers on the ground, participants were required to stand in the middle of a sphere consisting of 8 loudspeakers, arrayed uniformly over 360 degrees at a distance of 1 meter, and to identify the loudspeaker thought to have emitted the reverse alarm (Figure 1). Presentation levels were 75 dBA for the background noise (sawmill wood shavings) and the reverse alarms, with all signals calibrated to yield a signal-to-noise ratio of 0 dB in the « on » portion of the alarms. Prior to testing, familiarization was performed to ensure alarm audibility and task comprehension. Head and upper body movements were allowed.

Participants in each group (earplugs, earmuffs and double protection) were required to identify the source of the reverse alarm (tonal or broadband) in four listening conditions: 1) ears uncovered, 2) safety helmet alone, 3) hearing protection alone, and 4) combined use of hearing protection and safety helmet. Given the 2 repeated-subject factors (Alarm and Listening condition), sound localization was assessed in a total of 8 experimental conditions (2 alarms x 4 listening conditions). In each experimental condition, 24 reverse alarm signals were presented randomly from the 8 loudspeakers (3 times per loudspeaker). Signal duration was 0.990 seconds for the broadband alarm and 0.770 seconds for the tonal alarm, corresponding to one full cycle of each stimulus. Background noise occurred randomly between 2 and 8 seconds before the alarm.

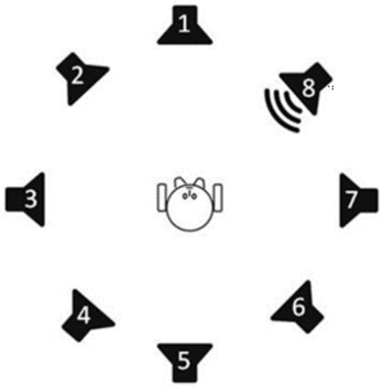

Figure 1: Experimental set-up for sound localization.

The free online version of the PEBL Psychological Test Battery (http://pebl.sourceforge.net/battery.html) was used to administer the main task, the Tower of London Test, which is commonly used in neuropsychology to assess cognitive functions involved in planning and involves reproducing a given pattern using a series of colored disks.

RESULTS

In each of the 8 experimental conditions, localization performance was expressed as the percent correct identification of the loudspeaker from which the alarm was emitted (number of correctly identified loudspeakers / 24 trials x 100). To explore the effect of personal safety equipment on sound localization, a repeated measures ANOVA was performed separately for each group (earplugs, earmuffs and double protection), with two intra-subject factors: 1) alarm type (2 levels: tonal and broadband alarms) and 2) listening condition (4 levels: ear uncovered, safety helmet alone, hearing protection alone and combined used of hearing protection and safety helmet). Results are summarized for each group in Figures 2 to 4.

Group 1 - Earplugs

Figure 2 displays percent correct scores for sound localization when earplugs are used by normal-hearing individuals. Performance with the broadband alarm proved superior than with the tonal alarm in all listening conditions, with differences in performance ranging from 23% in the double protection condition to 37% with ears uncovered.

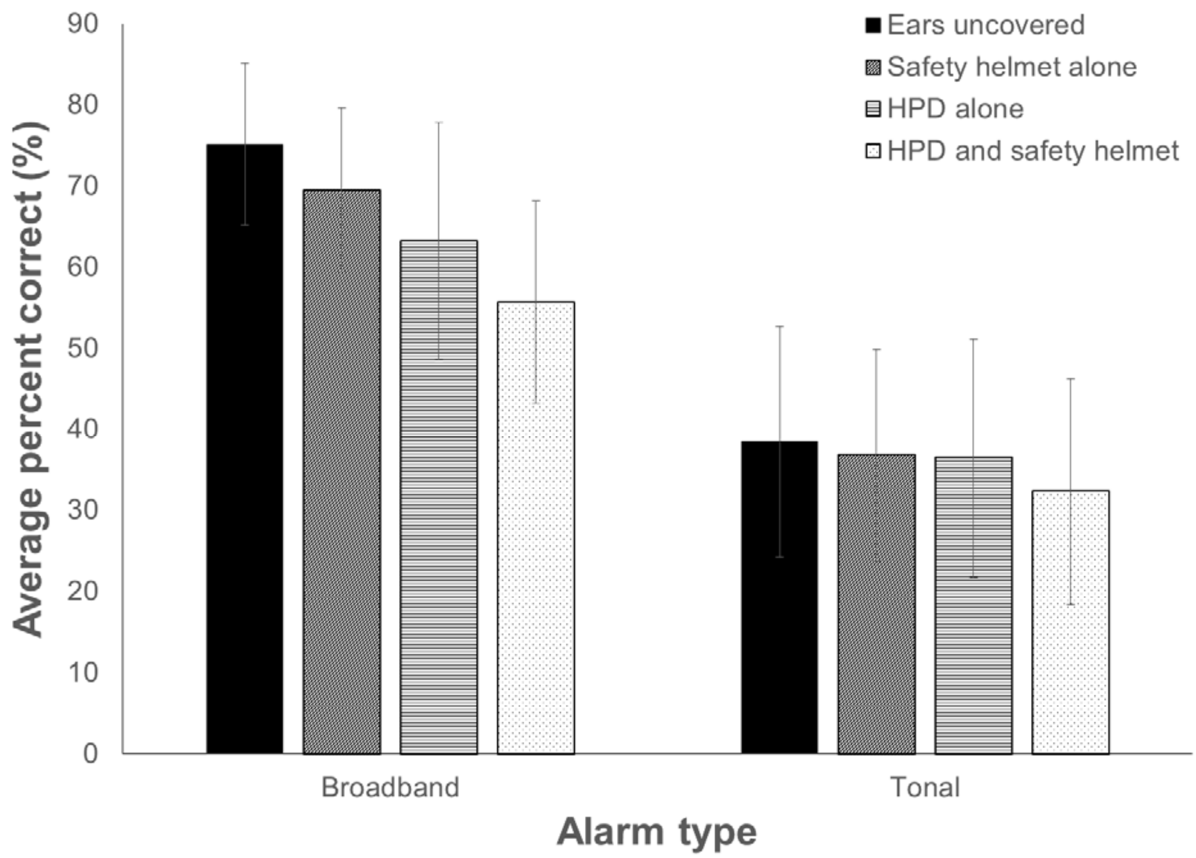

Figure 2: Average percent correct scores (± 1 standard deviation) for sound localization when passive earplugs are used by individual with normal hearing.

When comparing performance across the different listening conditions, a significant effect was found for the broadband alarm but not for the tonal alarm. Indeed, for the tonal alarm, the largest difference in performance across conditions was 6% (ears uncovered > double protection). For the broadband alarm, significant differences were obtained between the following pairs:

- ears uncovered > hearing protection alone (12%)
- ears uncovered > combined use of hearing protection and safety helmet (19%)
- safety helmet alone > combined use of hearing protection and safety helmet (14%)
- hearing protection alone > combined use of hearing protection and safety helmet (8%)

Group 2 - Earmuffs

The performance of normal-hearing individuals wearing earmuffs is summarized in Figure 3. In all listening conditions, performance is superior with the broadband alarm compared with the tonal, with differences ranging from 31 to 38%. When comparing performances across listening conditions, significant differences between average performances across both alarm types were noted in the following pairs:

- ears uncovered > hearing protection alone (15%)
- ears uncovered > combined use of hearing protection and safety helmet (20%)
- safety helmet alone > hearing protection alone (14%)

- safety helmet alone > combined use of hearing protection and safety helmet (24%)
- hearing protection alone > combined use of hearing protection and safety helmet (5%)

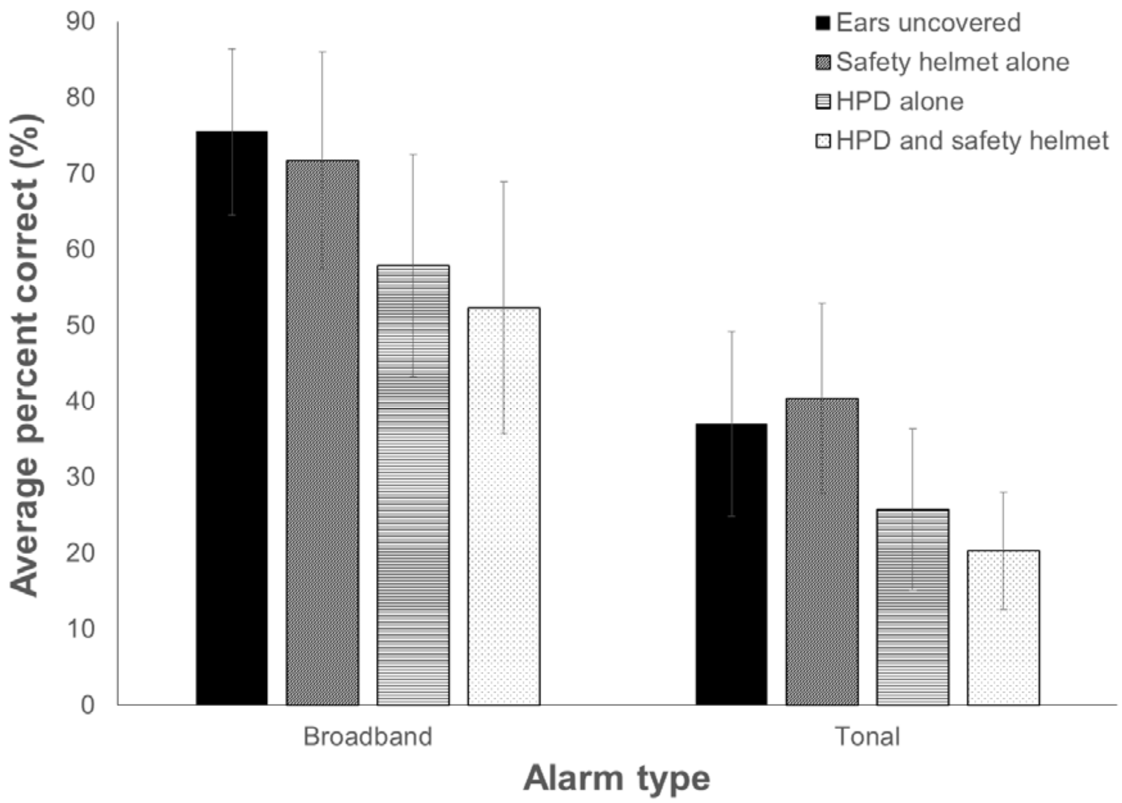

Figure 3: Average percent correct scores (± 1 standard deviation) for sound localization when passive earmuffs are used by individual with normal hearing.

Group 3 – Double protection

Finally, results obtained with double hearing protection are displayed in Figure 4. Performance with the broadband alarm proved superior than with the tonal alarm in two of the four listening conditions. While the broadband alarm outperformed the tonal alarm with ears uncovered (by 34%) and with use of a safety helmet alone (by 31%), performance for both types of alarms (ranging from 14 to 18%) fell close to chance level (1/8 = 12.5%) in conditions where double protection was used, with and without a safety helmet.

When comparing performance across the different listening conditions, a significant effect was found for both the broadband and the tonal alarms in the following pairs:

- ears uncovered > hearing protection alone (52% for broadband; 23% for tonal)
- ears uncovered > combined use of hearing protection and safety helmet (57% for broadband; 22% for tonal)
- safety helmet alone > hearing protection alone (50% for broadband; 23% for tonal)
- safety helmet alone > combined use of hearing protection and safety helmet (54% for broadband; 22% for tonal)

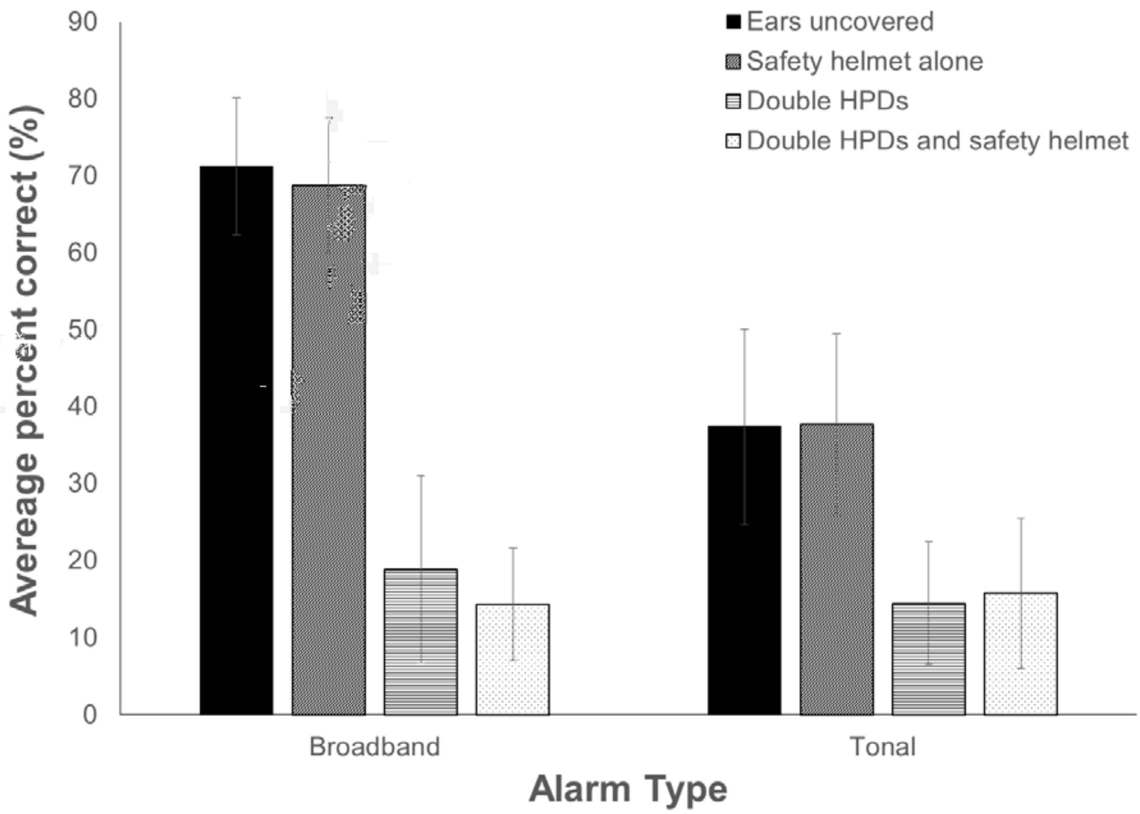

Figure 4: Average percent correct scores (± 1 standard deviation) for sound localization when passive double protection is used by individual with normal hearing.

It should be noted that all groups performed similarly in the conditions which were identical across groups (ears uncovered and safety helmet alone). Without HPDs, average performance across all 3 groups was 74% for the broadband alarm and 38% for the tonal alarm. Wearing only a safety helmet, average performance was 70% for the broadband alarm and 38% for the tonal alarm. No significant difference was found between performance ears uncovered and when a safety helmet is used alone. While localization accuracy for the broadband alarm is doubled compared to that of the tonal alarm, a finding consistent with the Nélisse et al. [11] study, use of a safety helmet does not seem to disrupt sound localization cues, at least when HPDs aren't used.

Differences across HPD groups

It seems obvious from Figures 2 to 4 that earplugs are less detrimental to localization than earmuffs and double protection, and that double protection virtually brings localization accuracy down close to chance levels. Performance with the broadband alarm proved superior than with the tonal alarm for the earplugs (by 27%) and earmuffs (by 32%), but not when double protection is used.

For the broadband alarm, average performance is greater with earplugs than with double protection (by 44%), and with earmuffs than with double protection (by 39%). No significant difference was found between earplugs and earmuffs. For the tonal alarm, all groups were found to be significantly different from one another, with earplugs outperforming earmuffs (by 11%) and double protection (by 22%), and with earmuffs outperforming double protection (by 11%).

Similar trends were found when a mixed design repeated measures ANOVA was carried out using data in the HPD with safety helmet condition.

DISCUSSION

Consistent with previous research findings [3,11], localization accuracy is significantly greater with the broadband alarm than with the tonal alarm. Across all listening conditions and HPD groups, differences in average percent correct scores between both alarms ranged from 23 to 38%, except in conditions of double protection (with and without a safety helmet) where performance for both alarms was similar and dropped to chance level.

As this study replicated the protocol used by Nélisse et al. [11], with the inclusion of HPDs and a safety helmet, it is interesting to compare overall performance across both studies for the listening condition without the use of personal safety equipment. In the current study, average performance across all 3 groups for ears uncovered was 74% for the broadband alarm and 38% for the tonal alarm, results similar to those obtained in the Nélisse et al. [11] study (83% and 42% for the broadband and tonal alarms, respectively).

Also consistent with previous literature findings, passive HPDs appear to disrupt sound localization. Indeed, performance with HPDs was significantly worse than without (with differences ranging from 12 to 52%), except when earplugs are used in combination with the tonal alarm. Double protection is most detrimental and reduces localization abilities to values close to chance performance. Finally, earplugs generally outperform earmuffs, at least with the broadband alarm.

While passive HPDs significantly impact sound localization, the safety helmet used in this study had a more limited effect. Without HPDs, results with and without the safety helmet were similar in all three subject groups. With HPDs, the addition of a safety helmet had a small (5-8% reduction in performance) but significant effect in a few conditions (for the broadband alarm with earplugs and for both alarms with earmuffs).

CONCLUSION

The use of personal safety equipment is common in many workplaces. This study investigated the use of passive HPDs and a safety helmet on the sound localization of two types of reverse alarms (broadband and tonal). While the safety helmet had a more limited effect on sound localization, passive HPDs were shown to significantly disrupt localization cues. While it is anticipated that reduced performances occur mainly as a result of increased localization errors in the front/back dimension, further analysis of the results are warranted to confirm this assumption.

In workplaces where good sound localization abilities are essential, the use of a safety helmet does not seem to be contra-indicated. However, double protection is to be avoided and earplugs appear to be the HPD of choice.

Studies on a broader range of safety helmets with different configurations are warranted as their effect on sound localization has thus far received little attention. Tasks requiring different degrees of cognitive resource allocation should also be investigated to reflect various situations encountered in real workplaces. Moreover, since hearing loss is common in workplaces where personal hearing protection such as HPDs are required, similar studies should be carried out with hearing-impaired individuals. Finally, with the increased development and availability of level-dependent (sound-restoring) HPDs, the effect of such devices on sound localization accuracy requires investigation as they may prove a viable option to limit noise exposure while maintaining adequate situational awareness, particularly in lower background noise levels.

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