The Effect on Earmuff Attenuation of Other Safety Gear Worn in Combination

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This study assessed the effect of other safety gear worn in proximity on the attenuation afforded by earmuffs attached to a hard hat. Seventy-two males and females participated: 24 under the age of 40 years with normal hearing, and 48 over the age of 40 years, half with normal hearing and half with bilateral high-tone hearing loss. Measurements were made with the ears unoccluded, with the muffs on hard hat alone, and with the muffs on hard hat in combination with safety glasses, an air-purifying half mask respirator or both glasses and respirator. They included (1) diffuse field hearing thresholds from 0.25-8 kHz, and (2) consonant discrimination in quiet and in 80-dB SPL speech spectrum noise. Attenuation was derived by subtracting the unoccluded from the protected hearing threshold at each frequency. Muff attenuation was within 6 dB of the manufacturer's specifications but decreased by as much as 5 dB when the glasses or respirator were worn and by 9 dB with both these devices. Males achieved 3 dB higher attenuation than females. However, hearing status had no effect. Consonant discrimination was significantly worse in noise. The impaired subjects performed more poorly when wearing the muff on hard hat but there was no additional effect of wearing the glasses and/or respirator. These results demonstrate that wearing other protective safety gear around the head can interfere with the hearing protection provided by earmuffs. They also confirm that for people with a hearing loss, the use of earmuffs may increase the communication handicap.

Keywords: hearing protection; hearing loss; communication handicap.

Introduction

Personal hearing protectors have been in common usage for the past forty years (Abel and Haythornthwaite, 1984). They provide an easily-implemented, effective, and low-cost method of minimizing the risk of hearing loss associated with exposure to high-level noise (Savell and Toothman, 1987; Brühl et al., 1994). Unfortunately, the attenuation actually achieved by the user generally falls short of the manufacturers' specifications. Specifications are typically based on optimal fitting of the device by trained personnel. Lesser observed "real-world" values may be due to poor fitting by the user, incorrect sizing, inadequate maintenance, slack headband tension, and incompatibility with other protective gear (Riko and Alberti, 1982; Abel et al., 1982; Abel et al., 1990; Berger and Lindgren, 1992; Berger et al., 1996).

Pre-existing hearing loss will not affect the amount of sound reduction achieved by the user, although it may affect his/her protected communication capability (Abel et al., 1985). The device attenuates the incoming signal, and coupled with elevated hearing thresholds, could prove detrimental to auditory perception. Gender, in contrast, has been shown to be a significant determinant of attenuation. Abel et al. (1988) found that for devices available in one size, the mean sound attenuation observed in women was significantly less than that for men. The difference was related to the cross-sectional area of the ear canal (Abel et al., 1990). The smaller the canal, the poorer the fit, and the less the attenuation achieved. Poor fit is not confined to plugs. Individual users may also experience problems with earmuffs, due to inadequate sizing of the ear cup, headband or hard hat attachments (Gasaway, 1985).

A potential drawback associated with hearing protector utilization is interference with the performance of auditory tasks. These include the detection, discrimination and localization of auditory warning signals, and speech communication. Sounds may be more difficult to perceive and distinguish, and if perceptible, possibly distorted, as a result of alterations of temporal and spectral features due to the physical features of the device and its attenuation characteristic (Casali, 1989). The extent to which these factors will affect performance may further depend on the characteristics of the listener, in particular her/his hearing status, age and fluency with the test language, as well as the presence of background sounds and reverberation of the listening environment (Abel, 1995). The general consensus from the laboratory studies conducted to date is that in normal-hearing listeners, the detection of auditory signals in noise backgrounds will not be negatively affected by the wearing of hearing protective devices (Wilkins and Martin, 1987). Indeed, there is evidence that detection thresholds may decrease (i.e., hearing may improve) by 3-6 dB (Abel et al., 1985; Wilkins and Martin, 1987; Letowski and McGee, 1993). In contrast, hearing-impaired listeners may be disadvantaged, if the attenuated signal is below threshold (Abel et al., 1985; Robinson and Casali, 1995).

As in the case of signal detection, the effect of hearing protective devices on speech understanding is critically dependent on the hearing status of the individual (Bauman and Marston, 1986). Abel et al. (1982) found that for both normal-hearing listeners and those with bilateral sensorineural hearing loss, recognition scores for monosyllabic English words were poorer when presented in noise than in quiet. In normal listeners, unoccluded and protected performance were no different. In contrast, for the hearing-impaired group, the protectors resulted in a significant decrement. Non-fluency with the test language resulted in a decrement in performance of 10% to 20% across the various ear by background listening conditions tested, regardless of hearing status.

Relatively few studies have examined the effect on hearing protector attenuation of other safety equipment worn in combination (e.g., Chung et al., 1983; Ribera et al, 1996; Wagstaff et al, 1996; Berger, 2000). The Canadian standard on hearing protection (CSA Z94.2-94) cautions that "the type of protector that best suits a person will depend upon other equipment he must wear (e.g., safety helmet, eyeglasses, and respirator)." The main concern is that the utilization of other devices worn in close proximity might interfere with the seal of the muff to the ear, thereby compromising its sound reduction capability. However, there is little objective documentation of this outcome. In a recent study by Wagstaff et al. (1996), the understanding of digits and words in helicopter noise was assessed in young normal-hearing subjects fitted with a communication headset, with or without the addition of sunglasses. The noise was held constant at a level of 97 dBA, while the speech level was varied to achieve a wide range of speech-to-noise ratios. Performance with both types of speech materials was poorer when the glasses were worn. The authors argued that this effect was due to an enhanced masking effect from low-frequency noise leakage under the poorly sealed muff.

Rationale

Safety devices are typically worn in combination. Current North American and international safety standards do not address the impact of the interaction which might prove detrimental to the performance of each component. This research was designed to determine whether the sound attenuation afforded by hearing protective earmuffs would be compromised, if the device was worn in combination with other safety gear worn in close proximity. Combined usage of such devices has the potential of compromising the seal between the muff and the outer ear, resulting in noise leakage under the ear cup. Hearing thresholds and speech understanding in quiet and in noise were measured in subjects wearing a Class A muff (CSA Z94.2-94) mounted on a hard hat, either worn alone or in combination with commonly used safety glasses and/or an air-purifying half-mask respirator. Both males and females were tested to allow an assessment of gender differences in hearing protector effectiveness. Within each gender group, the results of young and middle-aged subgroups with normal and impaired hearing were compared to assess the implications for worker safety of age and pre-existing hearing loss.

Methods and Materials

Experimental Design

Seventy-two working-aged adults (36 males and 36 females) were tested. Each gender group was comprised of 12 normal-hearing adults under the age of 40 years and 24 adults who were 40 years of age or older, 12 with normal hearing and 12 with moderate bilateral sensorineural high-tone hearing loss. Each subject was tested under five ear conditions: (1) UN-with the ears unoccluded, (2) M-with Class A muffs (Aearo Peltor H7P3E) attached to a hard hat (LR46 with 6 pt suspension), (3) MR-with the muffs on hard hat and an air-purifying half-mask respirator (MSA Comfo Classic with twin GMA air vapour filter cartridges), (4) MG-with the muffs on hard hat and safety glasses (Aearo Nassau Plus Eye Wear), and (5) MGR-with the muffs on hard hat, safety glasses and respirator. These devices were fitted by a trained technician, so that the effects could be evaluated with best fit. The unoccluded condition was presented first, followed by the four protected conditions in random order.

Within each ear condition, measurements were made of (1) diffuse-field hearing thresholds in quiet for eight one-third octave noise bands centred at frequencies from 0.25 kHz to 8 kHz, and (2) consonant discrimination in quiet and in a continuous background of 80 dB SPL speech spectrum noise. The level of the noise, 5 dB below the requirement for hearing protector usage in the workplace (see CSA Z94.2-94), was chosen to comply with ethics review board stipulations that subjects should not be at risk during unoccluded listening. Also, our previous research had suggested that at higher noise levels, hearing impaired listeners might be unable to hear the speech with the ears protected (Abel et al., 1985). The speech was fixed at a raised conversational level of 75 dB SPL, modelling real world scenarios (Gasaway, 1985). Attenuation was derived by subtracting the unoccluded from the occluded hearing threshold for each frequency, within each of the protected conditions.

Subjects

Subjects were recruited by posting notices throughout the University of Toronto. Clinicians at several affiliated teaching hospitals advertised the study to their clinic patients with hearing loss. The study was open to men and women, 18-70 years of age, who were fluent in English. Prospective candidates were screened by telephone for a history of head injury, systemic disease and neurological disorders to rule out central auditory processing deficits and to ensure a basic level of functioning necessary for the performance and completion of the experimental tasks. Individuals under the age of 40 years were admitted to the study if their unoccluded diffuse-field hearing thresholds were less than 20 dB HL from 0.25-8 kHz. Individuals who were 40 years of age or older underwent a headphone hearing screening test prior to participation. Those with thresholds in each ear less than 25 dB HL at 0.5 and 4 kHz (Yantis, 1985) were admitted to the normal-hearing groups. Those with a clinical diagnosis of bilateral senorineural hearing loss and thresholds of 25-60 dB HL (worse ear) at 4 kHz and interaural differences no greater than 20 dB were admitted to the hearing-impaired groups.

Head circumference, a possible determinant of the fit of the muff and thus the attenuation realized, was also measured in each participant. Summary statistics are presented in Table 1. Averaged across male and female groups, respectively, head circumference was found to be relatively greater in males, but only by 2 cm.

Table 1. Head circumference by group

Group	N	Head Circumference (cm.) Mean	SD	Min	Max
Normal Hearing					
Young Males	12	56.5	1.4	54	59
Young Females	12	57.1	1.3	55	59
Older Males	11+	59.0	1.9	55	62
Older Females	12	56.2	2.2	53	61
Impaired Hearing					
Older Males	12	59.3	2.1	55	62
Older Females	12	55.5	2.0	53	61

+Measurement unavailable for one subject.

Apparatus

The apparatus has been previously described in detail (Giguère and Abel, 1990). Subjects were tested individually within a semi-reverberant sound proof booth (3.5m by 2.7m by 2.3 m) that met the requirements for hearing protector testing specified in ANSI S12.6-1997. The ambient noise was less than the maximum permissible for audiometric test rooms given in this standard. Pure-tone stimuli used for hearing screening were generated by a Hewlett Packard multifunction synthesizer (HP 8904A), and presented monaurally over a Telephonics TDH-49P headset. The one-third octave noise bands for the experimental hearing threshold task were generated using a Bruel & Kjaer noise generator (B&K 1405) and band pass filter (B&K 1617). The speech test was commercially available on audio cassette and was played by a Yamaha twin cassette deck (KX-W900/U), either in quiet or mixed with the pre-recorded speech spectrum noise. The one-third octave noise bands, speech materials and speech spectrum noise background were presented free-field over a set of three loudspeakers (Celestion DL10) positioned to create a uniform sound field. Stimulus selection and fine adjustment of stimulus level, duration and envelope shaping were accomplished by means of a Coulbourn Instruments modular system. The output was fed to a pair of manual range attenuators (HP 350D) and Rotel mixer amplifier (RA 1412). For the measurement of hearing thresholds, subjects signified their responses by means of a hand held push-button switch. Paper and pencil were used for the consonant discrimination task. Devices were controlled from a personal computer (AST Premium 286) via IEEE-488 and Lablinc interfaces, and digital I/O lines.

Procedure

Diffuse-field *hearing thresholds* were measured once for each of eight one-third octave noise bands, centred at frequencies ranging from 0.25kHz to 8 kHz. A variation of Bekesy tracking was used (Yantis, 1985). For each threshold determination, the stimulus was pulsed continuously at a rate of 2.5 per second. The pulse duration was 250 ms, including a rise/decay time of 50 ms. Subjects were instructed to depress an on/off push-button switch whenever the pulses were audible, and to release the switch when they could no longer be heard. The sound level of consecutive pulses was increased in steps of 1 dB until the switch was depressed and then decreased at the same rate of change until the switch was released. The tracking trial was terminated after a minimum of eight alternating intensity excursions with a range of 4 to 20 dB. Hearing threshold was defined as the average sound level of the eight final peaks and valleys.

Speech understanding was investigated using the Four Alternative Auditory Feature Test (FAAF) of consonant discrimination developed by Foster and Haggard (1979). For each of the five ear conditions, the subject was given a typewritten list of 80 sets of four common monosyllabic words in the form of consonant-vowel-consonants. Half the sets, randomly throughout the list, contrasted the initial and half the final consonant (e.g., wet, bet, get, yet OR bad, bag, bat, back). One word from each set was presented over the loudspeakers, and the subject was required to circle the alternative heard. The first half of each list was presented in quiet and the second half in noise. Five different lists were available on audio cassette. These were counterbalanced across the five ear conditions and subjects within groups.

Results

Hearing Thresholds

The results of the hearing threshold (dB SPL) measurements are presented in Figure 1. The mean hearing threshold is plotted as a function of frequency with ear condition as the parameter (UN-unoccluded, M-muff on hard hat, MR-muff on hard hat/respirator, MG-muff on hard hat/glasses, and MGR-muff on hard hat/glasses/respirator). The data for males and females have been averaged for the normal-hearing young and older and impaired older groups, respectively. Measurements could not be made at 8 kHz in two of the impaired males with the muff on hard hat, in one of the impaired males with each of the muff on hard hat/respirator, muff on hard hat/glasses, and muff on hard hat/glasses/respirator combinations, in one of the impaired females with the muff on

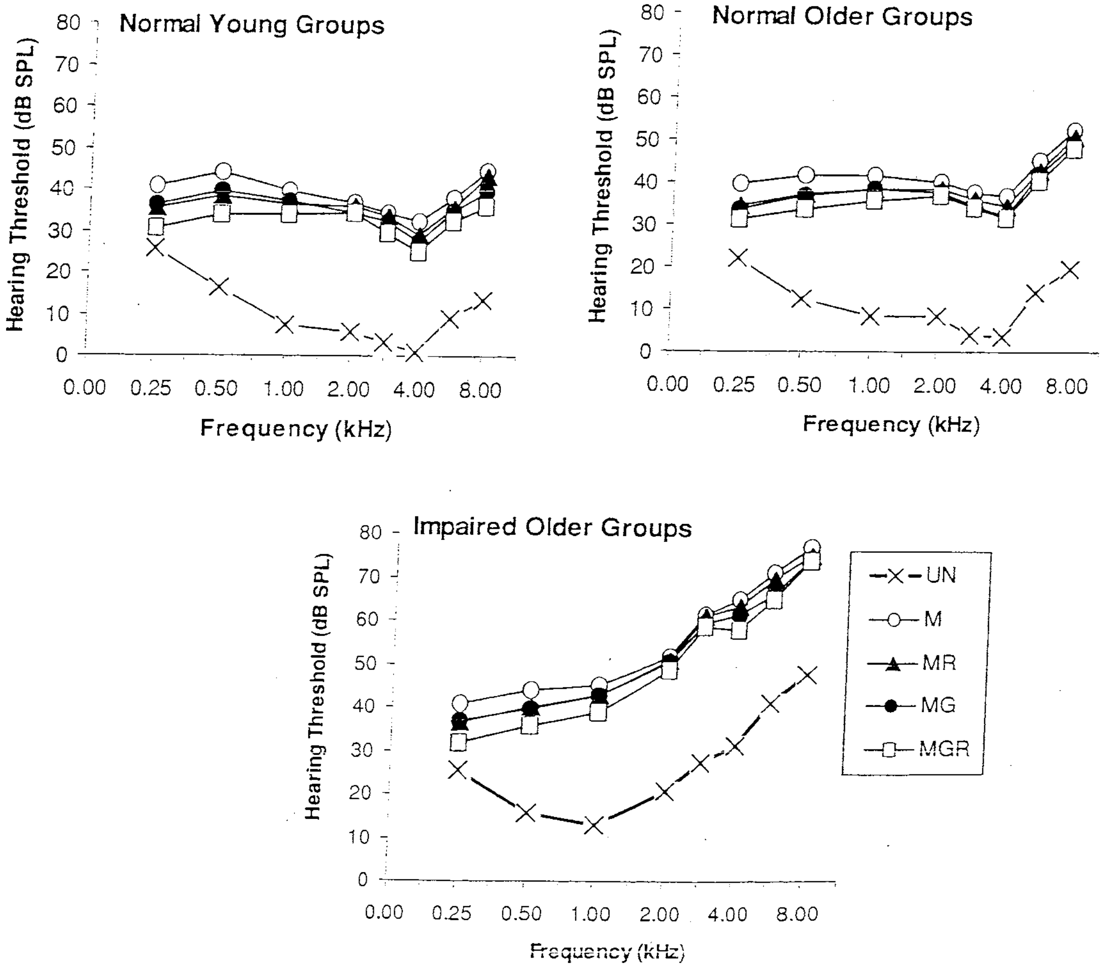

Figure 1. Hearing thresholds in three groups. Effects of ear condition, age and hearing loss.

hard hat, and in two of the impaired females with the muff on hard hat/respirator combination. In these cases, thresholds exceeded the 95 dB SPL limit of the audio system. The standard deviations associated with the means ranged between 3 and 13 dB. The magnitude of the standard deviation did not appear to change systematically with changes in age, gender or hearing status.

In order to determine the statistical significance of variation in group, ear condition, and stimulus frequency on hearing threshold, a nested ANOVA was applied to the data (Daniel, 1983). This analysis showed significant effects of group [F(5,61)=33.2; p<0.0001], ear condition [F(4,244)=2167.2; p<0.0001], ear condition by group [F(20,244)=2.4; p<0.001], frequency [F(7,427)=77.9; p<0.0001], frequency by group [F(35,427)=19.1; p<0.0001), ear condition by frequency [F(28,1708)=110.8; p<0.0001], and ear condition by frequency by group [F (140,1708)=1.4; p<0.002]. Post hoc pairwise comparisons of significant factors using Fisher's LSD test (p<0.05) indicated that, averaged across groups and frequencies, hearing thresholds were lowest in the unoccluded condition, followed by the muff on hard hat/respirator/glasses combination, followed by the muff on hard hat/respirator and muff on hard hat/glasses combinations which were no different. Thresholds were highest with the muff on hard hat alone. In the protected ear conditions, mean hearing thresholds in the normal-hearing young and older groups were no greater than 45 dB SPL and 56 dB SPL,

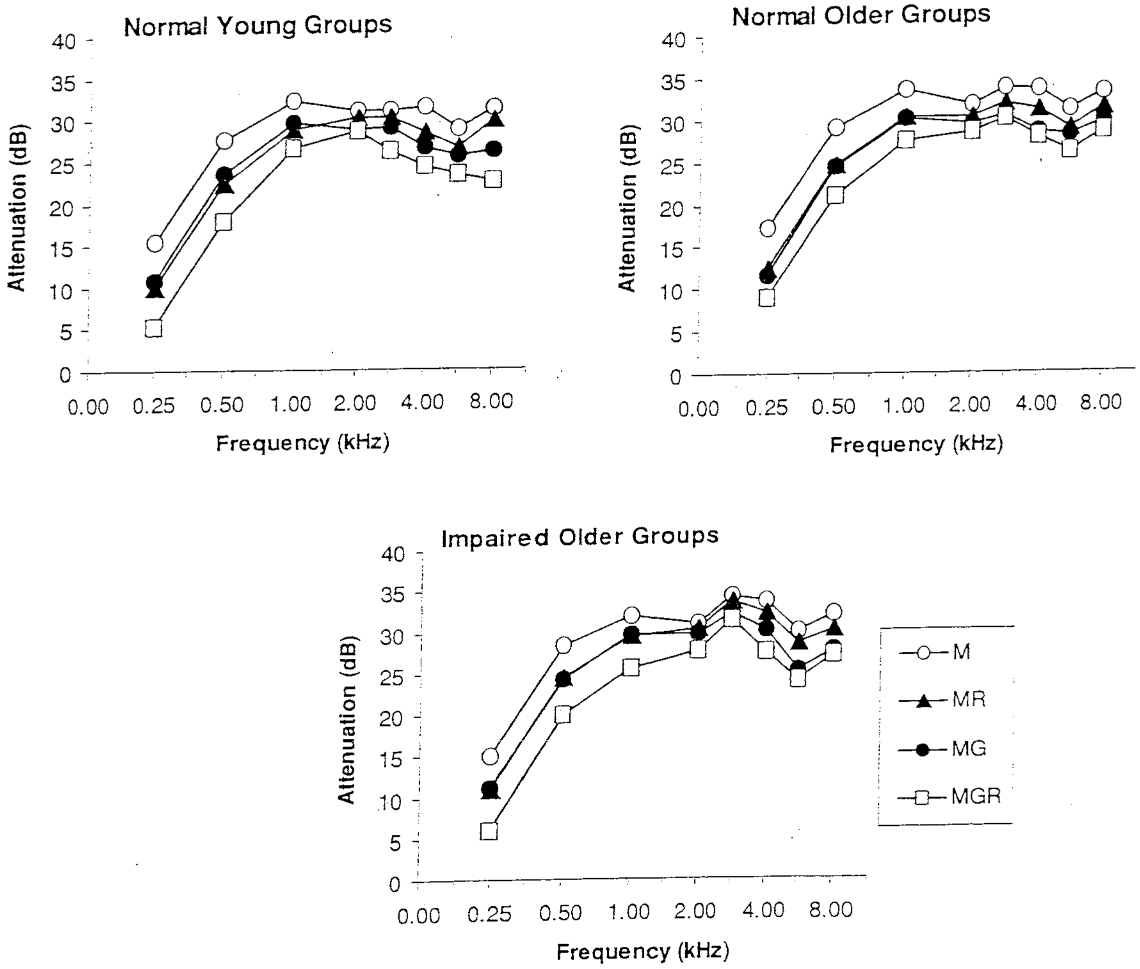

Figure 2. Attenuation in three groups. Effects of protector condition, age, and hearing loss.

Table 2. A comparison of the attenuation achieved by males and females fitted with Aearo Peltor H7P3E muffs mounted on a LR46 hard hat and the manufacturer's specifications.

Freq. (kHz)	Manufacturer's Specification	Males (N=36)	Females (N=36)
0.25	18.8(2.0)[a]	17.3(3.5)	14.6(4.8)
0.5	28.1(3.0)	29.4(4.0)	27.5(5.4)
1.0	36.2(2.1)	33.4(3.9)	31.8(4.4)
2.0	35.6(2.2)	32.6(4.6)	29.8(3.5)
3.15	38.4(2.3)	34.3(4.3)	31.8(4.3)
4.0	35.0(2.1)	34.7(3.5)	31.1(4.9)
6.3	35.5(2.1)	30.4(3.3)	29.7(3.4)
8.0	36.4(2.4)	33.2(4.0)	31.0(4.9)

[a] Mean(SD)

respectively. In comparison, thresholds in the hearing-impaired groups were as high as 78 dB SPL.

Sound Attenuation

The mean attenuation, derived by subtracting the unoccluded from the protected hearing threshold within subject in each of the four protector conditions, is presented in Figure 2. Attenuation is plotted as a function of stimulus frequency, with the protector condition as the parameter. The data have been averaged for males and females within each of the normal young and older and impaired older groups, respectively. In order to determine the statistical significance of variation in group, protector condition, and frequency, a nested ANOVA was applied to these data. The results showed significant effects of group [F(5,61)=4.3; p<0.002], protector condition [F(3,183)=104.2; p<0.0001], frequency [F(7,427)=387.7; p<0.0001], frequency by group [F(35,427)=1.8; p<0.006], protector condition by group [F(21,1281)=12.2; p<0.0001], and protector condition by frequency by group [F(105,1281)=6.8; p<0.04. The protector condition by group interaction was not significant. Post hoc pairwise comparisons indicated that females achieved 3 dB less attenuation than males. There was no difference due to age or hearing status. Averaged across protector conditions, attenuation showed significant increases as frequency increased from 0.25 kHz to 1 kHz and then remained constant, except for a dip at 6.3 kHz. Averaged across groups and frequencies, the least attenuation was achieved with the muff on hard hat in combination with the glasses and respirator and the greatest attenuation was achieved with the muff on hard hat alone. The muff on hard hat/respirator and muff on hard hat/glasses combinations fell midway between and were not significantly different from each other. The range in attenuation across these conditions was greatest at 0.25 and 0.5 kHz (9 dB) and least at 2 and 3.15 kHz (3-4 dB).

A comparison of the attenuation achieved with the muffs on hard hat alone by males and females, irrespective of age and hearing status, and the manufacturer's specifications is shown in Table 2. While the values observed in the present study were consistently lower than the manufacturer's specifications, the difference was at most 6 dB across the frequencies and gender groups tested. The range of values was also somewhat greater in the study sample than those reported by the manufacturer. The study standard deviation was 3-5 dB compared with the manufacturer's 2-3 dB.

In order to determine whether head circumference might account for the greater variance, and also the male/female differences in attenuation, Pearson correlation coefficients were calculated between head circumference and attenuation for each combination of protector condition and stimulus frequency for the 35 males and 36 females for whom data were

Table 3. Statistically significant correlations between head circumference and attenuation in males and females

Group	Protector Condition	Freq. (kHz)	r	p
Males (N=35)	M	3.15	+0.39	0.05
	MR	3.15	+0.42	0.05
	MGR	3.15	+0.38	0.05
Females (N=36)	M	2.0	+0.41	0.05
	MR	2.0	+0.45	0.01
	MGR	1.0	+0.33	0.05

available. Significant outcomes ($p<0.05$) are displayed in Table 3. In males, the larger the head size, the greater the attenuation achieved at 3.15 kHz with the muff on hard hat, muff on hard hat/respirator and muff on hard hat/glasses/respirator. In females, positive correlations between the two outcome measures were observed at 2 kHz for the muff on hard hat and muff on hard hat/respirator, and at 1 kHz for the muff on hard hat/glasses/respirator. The

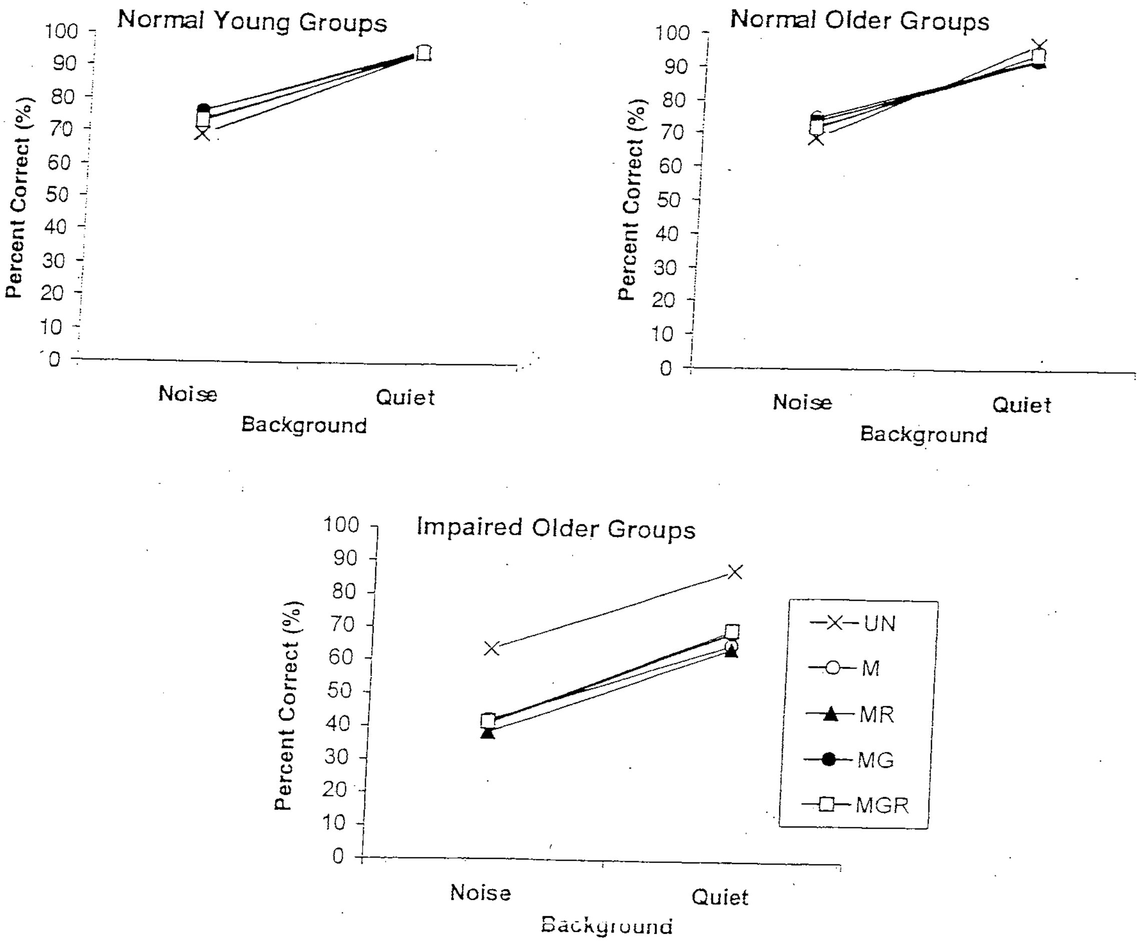

Figure 3. Final consonant discrimination in quiet and speech spectrum noise. Effects of ear condition, age, and hearing loss.

values of the correlation coefficients indicated that head size might account for at most 20% of the variance in attenuation.

Consonant Discrimination

A nested ANOVA applied to results of the consonant discrimination test showed significant effects of group [F(5,66)=45.4; p<0.0001], ear condition [F(4,264)=27.7; p<0.0001], ear condition by group [F(20,264)=15.3; p<0.0001], consonant [F(1,66)=65.8; p<0.0001], background [F(1,66)=1516.3; p<0.0001], background by group [F(5,66)=12.3; p<0.0001], ear condition by background [F(4,264)=3.4; p<0.01], consonant by background [F(1,66)=21.0; p<0.0001], and consonant by background by group [F(5,66)=4.2; p<0.002]. The mean percent correct observed for the final consonant is displayed in Figure 3 for each of the normal young and older groups and impaired older group, averaged across male and female subgroups.

Post hoc pairwise comparisons indicated that there was no effect of gender. However, the scores for the two impaired groups were significantly lower than those for the normal groups. For subjects with normal hearing, there was no difference between the unoccluded and protected scores. In contrast, for the hearing-impaired groups, the protected scores were significantly lower than the unoccluded scores, by 21% in quiet and 25% in noise, averaged across initial and final consonants. Protector combination was not a significant factor. All groups performed more poorly in noise than in quiet. Mean scores declined by 24% for all three groups in the unoccluded condition, and by 17% and 27% for the normal and impaired groups, respectively, in the protected conditions. In quiet, there was no difference between the outcomes for initial and final consonant contrasts. In noise, scores were significantly lower for the final constant contrast, by 8% in the normal groups and by 5% in the impaired groups.

To determine the relationship between protected speech understanding and hearing, Pearson correlation coefficients were calculated between the hearing thresholds observed at each of 0.25, 0.5, 1, 2 and 4 kHz, and each of the four FAAF test scores (initial consonant in quiet, final consonant in quiet, initial consonant in noise, and final consonant in noise), for each of the four protector conditions (M, MR, MG and MGR). The analyses were carried out first for all seventy-two subjects taken as a group, and subsequently for each of the normal-hearing young and older groups and the impaired older group, averaged across gender subgroups. The outcomes were scanned for cases where the correlation coefficient was significant at the 0.01 level and 0.65 or greater (indicating that at least 42% of the variation in speech score was accounted for the hearing threshold).

For the larger group of seventy-two subjects, these conditions were met only at 2 kHz and 4 kHz. For each of these stimulus frequencies, all sixteen correlation coefficients (four speech outcomes in each of four protector conditions) satisfied the stated criteria, and all were negative (the higher the threshold, the lower the FAAF score). For the normal-hearing younger group taken separately, there were no such instances, and for the normal older group only one such instance (the threshold at 0.25 kHz and the initial consonant score when the muff on hard hat was worn in combination with both the respirator and glasses). For the impaired group, there were four such instances: the 2-kHz threshold and the initial consonant in quiet or noise with the muff on hard hat/respirator combination, the 1-kHz threshold and the initial and final consonants in quiet with the muff on hard hat/glasses combination, and the 2-kHz threshold and the final consonant in quiet with the muff on hard hat/glasses/respirator combination.

Discussion

The main question addressed in this research was whether the attenuation provided by hearing protective earmuffs attached to a hard hat might be diminished if the device was worn in combination with other protective gear in close proximity. Previous research had demonstrated that if the seal of the muff with outer ear was compromised, the resulting leakage of sound under the ear cup would alter the performance of the device (Crabtree, 1996; Wagstaff et al., 1996). The devices chosen for the present study included safety glasses and an air purifying half-mask respirator both of which involve placement near the ear. The magnitude of the change in attenuation and the impact on signal detection and speech understanding were in line with previous findings.

The results of the study indicated that the wearing of either safety glasses or a half-mask respirator in combination with a Class A earmuff attached to a hard hat did indeed result in a significant decrement in attenuation. The greatest effect was observed when the muff was worn in combination with both the glasses and respirator. This outcome was frequency dependent, with the maximum decrement (9 dB) occurring at 0.25 kHz and 0.5 kHz. Smaller, although still statistically significant, decrements of 4-5 dB were observed in this frequency region with the muff on hard hat in combination with either of the other devices taken separately. The effect diminished as the stimulus frequency increased.

Hearing status did not influence the degree of attenuation achieved. This outcome was expected since attenuation is derived by subtracting the occluded from the protected hearing threshold at each frequency. Also as expected, the sound attenuation realized was frequency dependent. When the muff on hard hat was worn alone, attenuation increased linearly from 5-15 dB (depending on the protector condition) at 0.25 kHz to 25-35 dB at 1 kHz, and remained fairly constant from 1 kHz to 8 kHz. The statistical analyses showed that women achieved 3 dB less attenuation on average than men. However, for both males and females, the mean attenuation values observed were within 6 dB of the manufacturer's specifications at each of the eight frequencies tested. It must be noted that care was taken to achieve an optimal fit of the muff prior to applying the glasses and/or respirator. In many cases, best fit was achieved at the expense of the fit of the hard hat. Experience suggests that in real-world occupational settings, relatively greater attention would be given to the hard hat, with the likely result that muff attenuation would deviate to a greater extent from the manufacturer's specifications than observed in the present study. In both men and women, head circumference proved to be a significant, albeit small, correlate of outcome at selected frequencies. In men, the larger the head size, the greater the attenuation achieved at 3.15 kHz. In women, the effect was observed at 1-2 kHz. Measurements made with ANR headsets have demonstrated that leakage under the ear cup results in resonance below 250 Hz (Crabtree, 1996). However, the leakage path can also affect high frequencies (Crabtree, 2002). It has also been shown previously that women will achieve less benefit with hearing protective ear plugs that are available in only one size (Abel et al., 1988; Abel et al., 1990). Taken together, these results underscore the importance of considering personal anatomical variations in selecting hearing protection.

For all groups tested, hearing thresholds were significantly lower in the unoccluded than in any of the protected conditions, and significantly highest when the muffs on hard hat were worn alone. Regardless of the age of subjects or their hearing status, normal or impaired, the greater the sound attenuation afforded by the hearing protector or the protector in combination with other gear, the higher the hearing threshold. Averaged across the four groups of normal hearing listeners, protector conditions and stimulus frequencies, protected hearing thresholds ranged from 30-45 dB SPL. Thus, sounds were always comfortably audible. In contrast, for the two groups of hearing-impaired listeners, protected thresholds ranged from 36 dB SPL at 0.25 kHz to 50 dB SPL at 2 kHz to 75 dB SPL at 8 kHz. These results show that, in individuals with hearing loss, sounds above 2 kHz would have to be relatively loud in order to be just audible. Sounds signifying hazard would have a greater chance of being heard if they were at low frequencies.

Consonant discrimination was significantly poorer in the hearing-impaired than in the normal-hearing listeners. Both groups achieved lower scores in noise than in quiet. Based on the FAAF total score (which included both initial and final consonant contrasts), the difference was 18% for the normal listeners and 26% for the hearing impaired. Although noise was more detrimental for perception of the final consonant, the effect was relatively small at 6% on average. In normal listeners, performance was not affected by the wearing of hearing protection. In contrast, in the hearing-impaired, protected scores were lower by 23%, averaged across quiet and noise backgrounds. This finding is in line with previously published research (Abel et al., 1982; Abel et al., 1993). No differences were observed across the four protector conditions. This was likely because the effect of wearing the safety glasses and half mask respirator in combination was confined to the lowest frequencies tested. These were below the range normally considered important for speech understanding (Schill, 1985). Correlational analyses indicated that for the larger group of seventy-two subjects, only the high-frequency thresholds (2 kHz and 4 kHz) accounted for more than 40% of the variance in the speech scores within the various protector conditions. This is in line with the results of previous research (Humes and Roberts, 1990; Smoorenburg, 1992). For the hearing-impaired group taken separately, the region from 1-2 kHz appeared to be more relevant for communication capability.

In summary, the results of this study demonstrated that the protection afforded by Class A earmuffs attached to a standard hard hat for the prevention of noise-induced hearing loss was compromised when the device was worn in combination with other safety gear in close proximity. The decrease in attenuation was greatest at the lowest frequencies tested, i.e., 0.25 kHz and 0.5 kHz. The fit of the muff itself was also an important determinant of outcome. The attenuation achieved in individuals was related to the circumference of the head. This finding was not gender specific. Fit may also have been compromised by the hard hat attachment. The model chosen, as with most models marketed, did not allow for these two components to be locked into a position that would maximize the protection afforded by each. In order to achieve the maximum sound attenuation, the fit of the hard hat was disregarded. Had the sizing of the hard hat been a priority, the attenuation of the muff would likely have fallen short of the manufacturer's specification to much greater degree than was observed. While attenuation did not change as a function of hearing status, the detection of high-frequency stimuli and speech understanding were negatively affected by the wearing of hearing protectors in individuals with high-tone hearing loss.

Conclusions

1. In workplaces where low-frequency sound attenuation is an important consideration, and individuals are obliged to wear other head gear in combination with hearing protectors, it may be advisable to choose ear plugs instead of muffs. Plugs provide significantly more low-frequency attenuation than muffs and may be fitted without regard to other safety gear worn in close proximity.

2. Special attention must be paid to the sizing of all protective gear worn. In cases where hearing protective muffs and a hard hat are components of a single unit, it must be recognized that optimising the fit of either device may preclude best fit of the other.

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