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최 철 희

ABSTRACT

Hearing Threshold Shift and Speech Intelligibility Index of Personal Hearing Protective Devices

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The objective of this study is to investigate the effectiveness of the personal hearing protective devices in terms of the hearing threshold shift and the speech intelligibility index. The hearing threshold shift was used to quantify the protection effect of the personal hearing protective devices and obtained by subtracting the baseline threshold measured without the personal hearing protective devices from the hearing threshold measured with the personal hearing protective devices. The speech intelligibility index (SII) was used to predict and compare the potential benefits of each personal hearing protective device and obtained from the count-the dots method. A total of 6 college students aging from 21 to 25 years old were randomly recruited as subjects. Different types of personal hearing protective devices (earplug and earmuff) were used in this study. A statistically significant difference between the mean amount of threshold shift at low frequency (0.25-1 kHz) and that of high frequency region (2-8 kHz) was observed. The personal hearing protective devices (earplug and earmuff) were effective in protecting hearing from high frequency noises than low frequency noises. The use of earmuff was effective at the low frequency region while the use of earplug was effective at the high frequency region. In addition, the use of the earplug was more effective for the SII than that of the earmuff. The protection amount of the personal hearing protective devices (earplug and earmuff) ranged from 23 to 38 dB. However, the SII ranged from 32.6 to 54.5%, which indicates that the subjects misunderstood or missed the speech information ranged from 45.5 to 67.4% as mild to moderate hearing loss. This may lead to the development of new personal hearing protective devices which are effective for protecting hearing and understanding speech.

KEY WORDS : Personal hearing protective devices, Earplug, Earmuff, Hearing threshold shift, Speech intelligibility index, Noise-induced hearing loss, Acute acoustic trauma

INTRODUCTION

Noise-induced hearing loss (NIHL) is a permanent hearing impairment caused by continuous exposure to high levels of noise at or above 85 dB SPL over extended period of time while acute acoustic trauma (AAT) is a permanent hearing disorder resulting from a short exposure to intense impulse sounds from 100 to 150 dB SPL such as explosions and blasts (Rovig et al., 2004). Excessive exposure to hazardous noise levels is one of the most common causes of hearing loss. The Centers for Disease Control and Prevention called hearing loss caused by both noise and acute acoustic trauma as hidden disorders because approximately, there are some degree of hearing loss in nearly 17 in 1,000 children

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under 18 years of age and 17 percent (36 millions) of American adults (in more detail, 33 percent of Americans 65 to 74 years old, and 47 percent of those 74 and older).

The Occupational Safety and Health Administration (OSHA) recommended permissible daily exposure time (8 hours) to exposure to 85 dBA of noise and a 3 dB halving rule above the noise level (Choi et al., 2008). In addition, the OSHA required mandatory wearing of personal hearing protective devices to protect hearing when people were exposed to the noise levels of 85 dBA and above. However, the essential use of personal hearing protective devices in the noisy environments is meaningful under the thorough and complete investigation of the effect of personal hearing protective devices. In addition, when personal hearing protective devices are considered with a variety of pharmacological interventions developed as adjuncts for preventing or treating hearing impairment caused by noise and acute acoustic trauma, stronger synergistic efforts to protect hearing from noise and acute acoustic trauma will be produced. Therefore, the objective of this study is to perform audiological evaluation of the effectiveness of personal hearing protective devices in terms of hearing threshold shift and speech intelligibility index which can quantify the relative contribution of different frequency for understanding speech. The hearing threshold shift was used to evaluate the protection effect of the personal hearing protective devices while the speech intelligibility index was used to predict the potential benefits of each personal hearing protective device and compare the advantages obtained from one personal hearing protective device to that of another. This can lead to a development of new personal hearing protective devices to overcome the limitations of the current personal hearing protective devices and provide a new insight of personal hearing protective devices.

MATERIALS AND METHODS

1. Audiological Evaluation

1-1. Hearing Threshold Shift

The experimental procedures used in this study were reviewed and approved by the Catholic University of Daegu. A total of 6 college students aging from 21 to 25 years old were randomly participated as subjects. All subjects reported no positive history of head injury, ear surgery, and otologic disease or symptom. Their hearing thresholds were measured with two channel diagnostic audiometer (Acoustic Analyzer 1200, Starkey, Eden Prairie, MN, USA). Before wearing personal hearing protective devices, the baseline hearing thresholds were obtained. They were within normal range below 20 dB HL across the whole frequency range. Different types of personal hearing protective devices were used in this study. One was earplug [EP4(M size) Aero Company, Indianapolis, Indiana, USA] placed at approximately 5 mm from the tympanic membrane and the other was earmuff (Model 4000, Aero Company, Indianapolis, Indiana, USA). The earplug and earmuff used in this study were shown in Figure 1.

Figure 1. Different types (earplug and earmuff) of personal hearing protective devices

Hearing thresholds of both ears of each subject were measured with pure tone audiometer before and immediately after wearing personal hearing protective devices. Threshold shift (TS) was obtained as the difference between the baseline threshold and the hearing threshold measured with personal hearing protective devices.

1-2. Speech Intelligibility Index

The Speech Intelligibility Index (SII) has been used to quantify the proportion of speech information that is both audible and usable for a listener (Popelka, 1995). This refers to frequency importance function representing how each frequency region can contribute to speech intelligibility. In 1997, the term SII has originally been used to replace the more familiar term Articulation Index (AI) by the revision of the 1969 ANSI S3.5 standard titled American National Standard Methods for Calculation of the AI (ANSI S3.5, 1997; ANSI

S3.5, 2007). The method for calculating the SII has first been developed by Fletcher and his colleagues at Bell Telephone Laboratories to predict the impact of changes in frequency responses, distortion, and noise of telephone circuits on speech understanding (French & Steinberg, 1947, Lee & Kim, 2012). 2012). The general formula for calculating the SII is

$$SII = \sum_{i=1}^{n} I_i A_i$$

where the *n* refers to the number of individual frequency band, the I*i* indicates the importance of a given frequency band (*i*) to speech understanding, and finally the values for A_i (band audibility) ranging from 0 to 1 represents the proportion of speech cues that are audible in a given frequency band (ANSI, 1997, 2007).

After Pavlovic and his colleagues developed the original formula (Pavlovic & Studebaker, 1984; Palvovic et al., 1986; Studebaker et al., 1987), other researchers suggested an easy method for calculating the SII, called "the count-the-dot method" (Muller & Killion, 1990). In this method, there are 100 dots distributed among the different frequencies based on their importance in understanding speech. The number of dots at a particular frequency represents the relative importance of that frequency in speech intelligibility.

The count-the-dot method using 100 dots was used in this study to obtain the SII because this method can provide important advantages as follows: (1) to predict the amount of the hearing sensitivity loss for normal speech from the unaided audiogram, (2) to predict the benefit that personal hearing protective devices or hearing aids can provide, and (3) to compare effects of personal hearing protective devices as well as hearing aids (Mueller & Killion, 1990).

RESULTS

Based on the data of the pure-tone audiometer, the hearing threshold shift (TS) was calculated by subtracting the baseline threshold measured without the personal hearing protective devices from the hearing threshold measured with the personal hearing protective devices. This indicates the amount of hearing protection provided by the personal hearing protective devices. The greater the amount of TS is, the larger the amount protection of the personal hearing protective devices. Total threshold shift are shown as a function of frequency with two different types of personal hearing protective devices at both ears (Figure 2).

At low frequency regions (0.25-1 kHz), the amount of threshold shift is equal to each other while the amount of threshold shift increases as the frequency increases at high frequency regions (2-8 kHz). When a repeated-measures analysis of variance (ANOVA) was performed to compare the mean amount of threshold shift at the low frequency region from the high frequency region, there was a statistically significant difference between the mean amount of threshold shift at low frequency and that of high frequency region at $p < .00$ (Figure 3). The criterion for statistical significance used in this study was $p < .05$. This indicates that

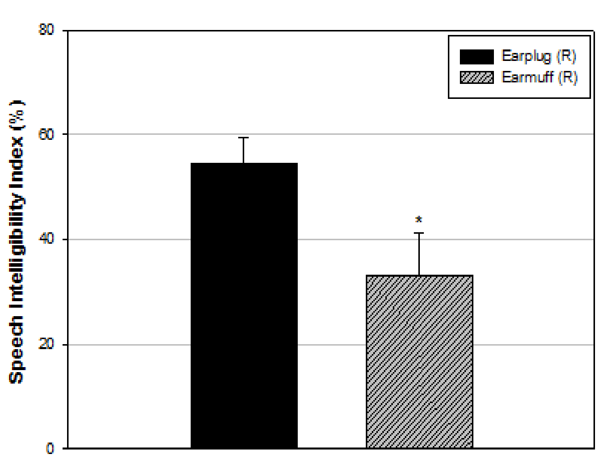

Figure 6. Speech Intelligibility Index (%) of different types (earplug and earmuff) at right ears

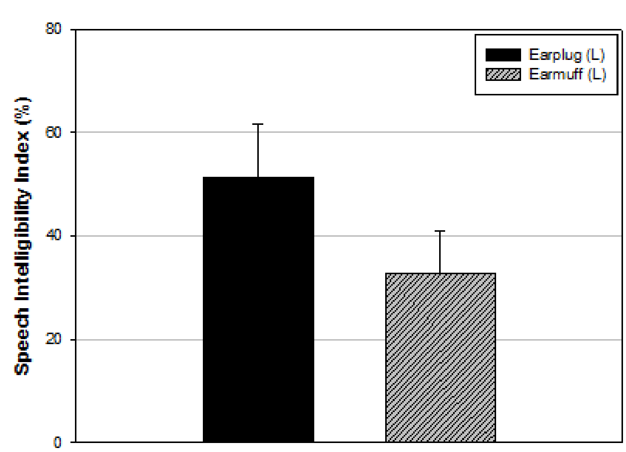

Figure 7. Speech Intelligibility Index (%) of different types (earplug and earmuff) at left ears

the personal hearing protective devices (earplug and earmuff) are well designed to protect hearing from high frequency noises than low frequency noises.

When the threshold shift obtained with one personal hearing protective device was compared to the other at both ears, the amount of the threshold shift measured with earplug at right ear was less than that of earmuff at low frequency region as shown in Figure 4. However, this was greater at high frequency region. As shown in Figure 5, the mean differences at each frequency were observed but a significant difference was only observed at 8 kHz ($p < .01$). Similar results at left ear were shown in Figure 5. As shown in Figure 6, the mean differences at each frequency were observed but there was no significant difference at any frequency. Although there is a statistically significant difference at only 8 kHz at right ear, there is an important trend that the use of earmuff as a personal hearing protective device is effective at the low frequency region while the use of earplug is effective at the high frequency region.

A significant difference in the SII percentage (%) obtained by using the count-the dot method was observed between the earplug and the earmuff at right ear at $p < .05$.

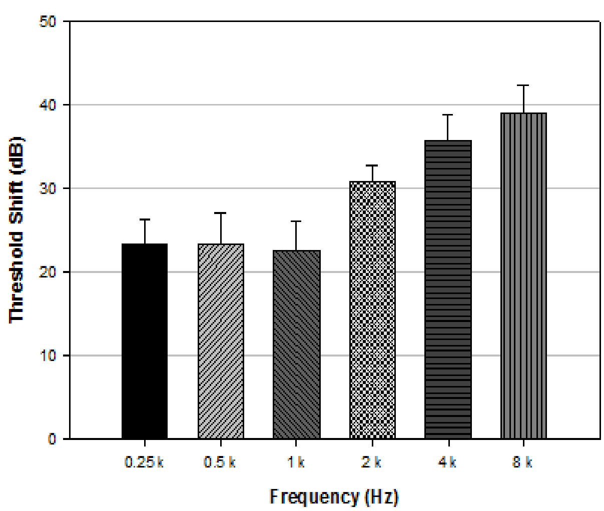

Figure 2. Means threshold shift (dB) at different frequencies (0.25-8 kHz) with two different types (earplug and earmuff) of personal hearing protective devices

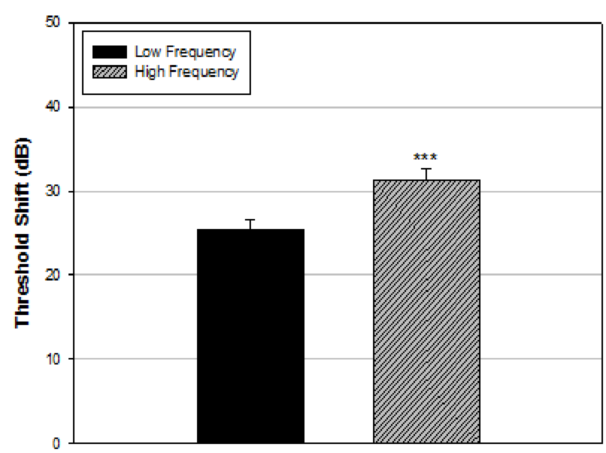

Figure 3. Mean threshold shift obtained from low frequency region (0.25-1 kHz) and high frequency region (2-8 kHz)

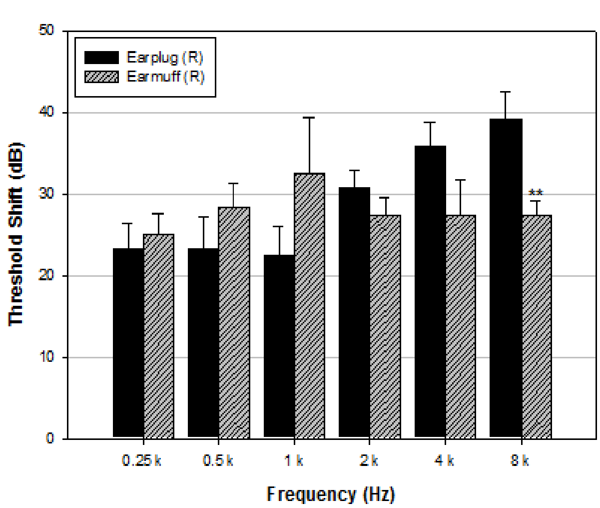

Figure 4. Mean threshold shift of different types of personal hearing protective devices at right ears

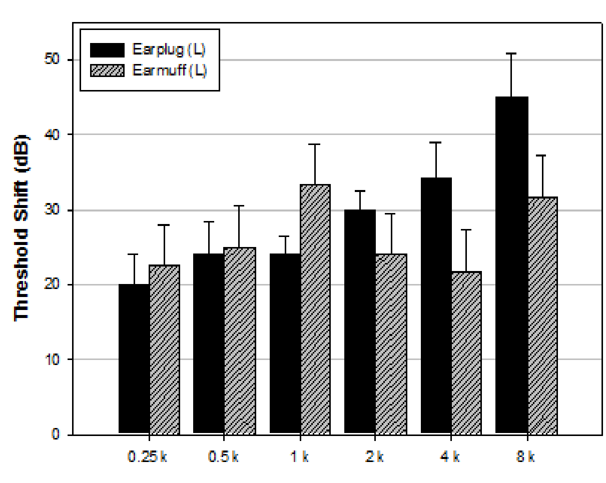

Figure 5. Mean threshold shift of different types of personal hearing protective devices at left ears

The amount (54.5%) of the SII obtained with the earplug was greater than that (33%) with the earmuff as shown in Figure 6. This trend was also observed at left ear as shown in Figure 7 except there was no significant difference between the earplug and the earmuff. This indicates that the use of the earplug is more effective for the SII than that of the earmuff.

DISCUSSIONS AND CONCLUSIONS

The objective of this study was to perform audiological evaluation of the effectiveness of personal hearing protective devices using the hearing threshold shift and the speech intelligibility index. The hearing threshold shift (TS) was used to assess the amount of hearing protection provided by the personal hearing protective devices while the speech intelligibility index was used to predict and compare the potential benefit of each personal hearing protective device. The results provide an interesting finding that the use of the earmuff was effective for hearing protection at the low frequency region (0.25-1 kHz) while the use of the earplug was effective for hearing protection at the high frequency region (2-8 kHz). This difference between earplug and earmuff may result from the natural resonances of the outer ear canal which shows a maximal gain of 15-20 dB at around 3 kHz and the concha which provides a second maximal gain at around 5-7 kHz (Shaw, 1974). The natural resonances of the outer ear canal and the concha remain unchanged with earplug while they may be collapsed with earmuff.

Generally, the effectiveness of personal hearing protective devices has been measured with the Noise Reduction Rating (NRR) providing users an easy method of determining the applicability of a personal hearing protective device for a particular environment (Berger, 1978). The NRRs indicate a significant difference in hearing protection between laboratory condition and real- world environment in a variety of personal hearing protective devices (Berger, 2000). The NRR of earplug was higher than that of earmuff in the laboratory condition while the NRR of earmuff was higher than that of the earplug in the real-world environment (Berger, 2000). The hearing protection in NRRs is expressed in the de-rating percentages to explain the difference between laboratory and real-world findings (NIOSH, 1998). The de-rating percentage was 25% for earmuff, 50% for foam earplug, and 70% for all other earplugs (NIOSH, 1998). However, ASHA (2007) recommended using the Noise Reduction Range instead of the Noise Reduction Rating due to overestimation of the real-world effectiveness expressed in the NRR. The NRR results shown in above studies were not consistent with those of our present study used the hearing threshold shifts and speech intelligibility index to estimate the effectiveness of personal hearing protective devices. These discrepancies may result from the differences in methods proving the effectiveness of personal hearing protective device.

The hearing protection amount of personal hearing protective devices in the hearing threshold shifts ranged from 23 to 38 dB while the SII was from 32.6 to 54.5%. This indicates that when personal hearing protective devices were used, users misunderstood or missed the speech information ranged from 45.5 to 67.4%. In other words, when people wore personal hearing protective devices, users could express themselves like people with mild to moderate hearing loss. This finding leads to a new need and insight for developing the personal hearing protective devices which are effective for protecting hearing and understanding speech. When a personal hearing protective device is selected by a worker, other factors such as a personal preference and convenience to use should be considered (Feuerstein & Chasin, 2009). Some workers like the convenience of earmuffs while others can prefer a soft foam earplug. Some workers do not like the sweat and pressure from earmuffs in summer and others can find difficulty inserting some types of earplug.

It should be noted that the SII was developed to indicate the proportion of audible speech information for English listeners and the frequency importance function for English intelligibility (Muller & Killion, 1990). The count-the-dot method was used in this study as an easy method to calculate the SII. However, this method can be limited for other language users. It was suggested that low-frequency information is more important for understanding Cantonese speech (Wong et al., 2007) and the frequency importance function of Korean monosyllabic words were different from that of English monosyllabic words (Lee & Kim, 2012).

This difference may result from the redundancy of test material, tonal nature of the other languages, or a combination of these factors (Wong et al., 2007).

Finally, a variety of pharmacological approaches using *N*-acetyl-L-cysteine (NAC), acetyl-L-carnitine (ALCAR), Phenyl-N-tert-butylnitrone (PBN), 4-hydroxy PBN (4-OHPBN), and a derivative of 4-OHPBN (HPN-07) have been developed to prevent or treat hearing loss or impairment caused by noise or acute acoustic trauma (Choi et al., 2008, 2011; Choi, 2011). These pharmacological interventions are very effective to prevent or treat hearing loss or impairment caused by noise or acute acoustic trauma. If the pharmacological methods are simultaneously used with new personal hearing protective devices, the synergistic effects will be stronger than each approach.

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