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The performance of active noise-canceling headphones in different noise environments

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ABSTRACT

The performance of active noise-canceling (ANC) headphones is typically determined in pink noise and expressed in terms of insertion loss (IL) curves. However, these curves may not be consistent with the actual noise environments. The aim of this study is to assess the performance of several commercial ANC headphones by comparing performance curves under different noise conditions with the respective IL curves obtained in pink noise. The results indicated that the passive performance remained consistent under different noise conditions. In contrast, the active performance diminished based on the noise environment, brand, and active noise controller. The decrease in performance was especially significant in highly transient events and resulted in a noise amplification extending to 20.4 dB. Therefore, the deviation between results of headphones tested in actual noise environments and those tested in pink noise strongly suggests that it is necessary to consider actual noise environments in future studies to obtain a more accurate evaluation of ANC headphones.

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1. Introduction

Headphones or earphones are an essential piece of equipment of daily commuters, and they allow commuters to select a listening experience based on their individual choice. In certain environments, such as construction sites or airports, this experience can be hampered owing to the ineffectiveness of passive devices to attenuate low-frequency and mid-frequency noise (<500 Hz) [1,2]. It may be necessary to alter certain design parameters to improve the attenuation capability of these headphones in this frequency range [3]. Unfortunately, this can eventually lead to a bulky and aesthetically unpleasing product that may not satisfy end-users. Thus, a few manufacturers incorporated active noise reduction technology in their products to overcome the limited noise attenuation capability of passive headphones. This feature is commonly known as active noise-canceling (ANC). The fundamental concept of ANC involves the design of an active noise controller to sense undesirable ambient noise and to generate an anti-phase signal to counter the same [4,5]. Consequently, the attenuation of low-frequency noise is achieved without requiring bulky passive headphones.

Although ANC technology is novel, it has a few disadvantages. Recently, Rudzyn and Fisher [5] investigated a wide range of commercial ANC headphones including both supra-aural and circum-aural types to determine their effectiveness in an overloaded and impulse noise environment. The results did not indicate any significant improvement in noise attenuation when the ANC feature was turned on, and this was consistent across all the studied headphones. This suggested that an individual could instead perceive higher ambient noise and increase the volume of their music to aid in improving audibility, and thereby inadvertently subject their auditory systems to potentially damaging volumes. The risk of occurrence of the fore-mentioned phenomenon is further heightened by the fact that it is often difficult to be conscious of exposure to loud music in a noisy environment [6].

In an effort to consider actual noise environments, a group of researchers evaluated ANC headphones in an aircraft cabin. Nevertheless, they focused on investigating the intelligibility of announcements as opposed to the acoustical performance of the headphones [7,8]. Other studies that considered actual noise environments focused on passive hearing protection devices with respect to the interests of industrial workers [9–12].

Although previous studies provide useful information on the evaluation of ANC headphones, there are evidently a limited number of extant studies that focus on evaluating the performance of ANC headphones in actual noise environments. Thus, in this study,

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several commercial ANC headphones were investigated to evaluate their performance in actual noise environments relative to those obtained in pink noise. The noise environments that were considered in the study include ambient noise at a construction site, an airport departure hall, an aircraft cabin during takeoff, and a bus cabin while commuting. The details of the commercial ANC headphones that were examined are presented in Section 2. Additionally, Section 3 discusses the results under each noise condition. In Section 4, the observations are discussed, and a conclusion based on earlier sections is presented in Section 5.

2. Materials and methods

2.1. Headphones

In this study, three commercial ANC headphones, hereinafter referred to as headphones, were investigated (Table 1). Bose QC25 and Sony MDR-10RNC are circumaural headphones that are designed to encompass pinnae with a large circular or ellipsoidal ear cushion. In contrast, the Sennheiser Momentum 2.0 is a supra-aural headphone that is designed to press against the pinnae with a circular ear cushion. Only a unit per model was assessed.

2.2. Experimental methodology

The experiment was performed in a reverberation chamber with a volume of 226.9 m^3. The average room temperature and relative humidity corresponded to 26 °C and 68%, respectively.

Fig. 1 provides a schematic representation of the experimental set-up for the respective noise fields. A sound quality head and torso simulator (B&K Type 4100) was used. As opposed to a cylindrical acoustic test fixture, the simulator allowed for a better representation of a human subject as it was designed to consider the anthropometry and acoustical characteristics of an average adult. The molded pinnae on the simulator provided directivity patterns that were similar to those of human ears. Two microphones were positioned considering the spatial separation between the human ears in which interference patterns caused by the head and torso were captured. Finally, a proprietary-designed cover (Fig. 2) was included to consider the change in reflections from the torso to increase the accuracy of directivity and body absorption [13,14]. However, it is important to note that B&K Type 4100 was designed for sound quality evaluation in automobile cabins and other sound optimization studies [14]. Thus, the results obtained from the simulator were only valid as relative measurements to aid comparisons between the different types of headphones.

The simulator and a data acquisition unit (B&K Type 3663) were placed on a standard test table positioned at the center of the chamber. Two active loudspeaker units (Yamaha DXR15) were each placed at a trihedral corner of the chamber to transmit the noise signal. Pink noise (50–12,800 Hz) was generated by a signal generator (B&K Type 1405) while other noise signals, such as construction noise, bus/aircraft cabin noise, and airport departure hall noise, were generated from audio tracks played on an audio system (Sony ZS-RS70BT). The audio tracks were either recorded from actual sites in Singapore or downloaded from the Internet. Additionally, a condenser microphone was placed at a distance of 1 m from each pinna of the simulator to record the sound pressure level (SPL) during each measurement. The heights of these microphones were aligned with the Frankfurt plane of the simulator. This adjustment was performed to ensure good agreement and consistency in the reverberant noise field during each measurement that was performed in the respective noise environments. Fig. 2 shows the actual experimental set-up in the reverberation chamber.

Table 1
List of headphones considered in the study.

Headphone type	Brand and model
Circumaural	Bose QC25
	Sony MDR-10RNC
Supra-aural	Sennheiser Momentum 2.0

Prior to placing a headphone on the simulator, a battery check was performed to ensure sufficient power was present to activate the ANC module. The headphone was carefully aligned with the scales around the pinnae and the top of the simulator to ensure consistent positioning. Additionally, the extended length of the headband was kept constant throughout the experiment to minimize inconsistent sealing. The passive and active performances of the headphones in each noise environment were measured six times for a duration of 30 s at a sampling rate of 32,768 Hz to ensure that the SPL of each noise source in the chamber for each measurement was considerably higher ($\geqslant$15 dB) than that of the background noise.

2.3. Calculation of passive and active performance

The recorded data was subsequently post-processed and computed in terms of insertion loss (IL), which is a parameter that is commonly used to evaluate the acoustical performance of hearing protection devices [5]. Specifically, IL is defined by Eqs. (1)–(3) in which the subscript f indicates a frequency-dependent term; L_O denotes time-averaged open ear SPL (without headphones); L_{C-OFF} denotes time-averaged SPL with headphones (ANC deactivated); and L_{C-ON} denotes time-averaged SPL with headphones (ANC activated). Additionally, IL_P, IL_T, and IL_A denote the passive, total, and active performance of the headphones, respectively.

$$IL_{P,f}(dB) = L_{O,f} - L_{C-OFF,f} \tag{1}$$

$$IL_{T,f}(dB) = L_{O,f} - L_{C-ON,f} \tag{2}$$

$$IL_{A,f}(dB) = L_{C-OFF,f} - L_{C-ON,f} \tag{3}$$

The arithmetic average between the SPL measurements at both the ears of the simulator were calculated based on the assumption of a diffuse field. An arithmetic average is acceptable and valid if the SPL difference between both ears falls below 5 dB.

Although the active performance of the headphones could be observed based on a comparison between IL_P and IL_T, the computation of IL_A allowed for an easier visualization of the effect of the frequency range on the noise level as a result of the active module. These IL curves were presented in a frequency spectrum as opposed to octave bands as it was probably not possible for the latter to illustrate the overall characteristic as clearly as the former.

3. Results

3.1. Performance curves of the headphones

The performances (passive, active, and total performances) of the headphones were determined by the IL of pink noise (50–10,000 Hz). The results were truncated at 10 kHz since energy levels beyond this frequency in the considered noise environments is too low to make meaningful observations. The background noise is important to demonstrate minimal electromagnetic interference (EMI) from the equipment and is presented in Fig. 3(a) along with the time-averaged open ear SPL of pink noise measured by the simulator. Fig. 3(b)–(d) present the performance curves of the headphones in terms of IL.

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