Applied Ergonomics 50 (2015) 50–55

Contents lists available at ScienceDirect

Applied Ergonomics

journal homepage: www.elsevier.com/locate/apergo

# Anthropometry of external auditory canal by non-contactable measurement

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ARTICLE INFO

*Article history:*
Received 20 November 2012
Accepted 28 January 2015
Available online 16 March 2015

*Keywords:*
External auditory canal
Computed tomography
Anthropometry

ABSTRACT

Human ear canals cannot be measured directly with existing general measurement tools. Furthermore, general non-contact optical methods can only conduct simple peripheral measurements of the auricle and cannot obtain the internal ear canal shape-related measurement data. Therefore, this study uses the computed tomography (CT) technology to measure the geometric shape of the ear canal and the shape of the ear canal using a non-invasive method, and to complete the anthropometry of external auditory canal. The results of the study show that the average height and width of ear canal openings, and the average depth of the first bend for men are generally longer, wider and deeper than those for women. In addition, the difference between the height and width of the ear canal opening is about 40% ($p < 0.05$). Hence, the circular cross-section shape of the earplugs should be replaced with an elliptical cross-section shape during manufacturing for better fitting.



## 1. Introduction

Article 21 of the Occupational Safety and Health Act Enforcement Rules defines workplaces with noise levels greater than 85 dB as specially or highly hazardous working environments or as including specially or highly hazardous working operations. Article 300 of the Occupational Safety and Health Facilities Regulations states that in environments where workers are exposed to noise levels greater than 85 dB for eight working hours a day or when the exposure is over 50%, employers shall require workers to wear effective earplugs, earmuffs, or other noise reduction apparatus. Although the soundproofing performance of earmuffs is superior to that of earplugs, especially for mid-to high-frequency domains, and although earmuffs conforming to the European standards (EN) provide better soundproofing effects, earplugs are more widely accepted by workers at actual worksites.

The requirements of EN 352-2 are concerned primarily with the physical and acoustic performance of the earplugs. It covers disposable, re-usable, custom moulded and headband ear-plugs. In the case of headband ear-plugs, the standard specifies sizing requirements which enable the great majority of the industrial population to be fitted satisfactorily by medium size range ear-plugs. Populations of other sizes may be accommodated by “small size range” or “large size range” ear-plugs, which are required to be accompanied by information regarding the range of sizes which they are designed to fit.

The United Kingdom commenced implementing noise reduction apparatus standards in 1994, and developed standards that countries within the Committee of European Standardization (CEN) must follow with regards to all European countries. The purpose of the hearing protection device is to reduce the damage caused by loud noises to workers and prevent subsequent hearing impairment. Factors that require consideration for hearing protection devices are the noise protection effects and whether the comfort

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http://dx.doi.org/10.1016/j.apergo.2015.01.008
0003-6870/

level is accepted by workers. In addition to being able to reduce the noise level that workers are exposed to, ideal earplugs must not affect the workers' experience of peripheral voices or sounds in the worksite, such as communication between staff, talking, and machinery and equipment operating conditions on work premises. An overprotection condition is more likely to cause ear canal discomfort, difficulties in conversation and verbal communication, and significantly reduces the workers' willingness to wear earplugs, thereby causing earplugs to lose their hearing protection effects. Moreover, existing earplugs in Taiwan are primarily imported. Foreign-made earplugs are generally a poor fit for the ear canal size of domestic workers or are even too large. However, because they have no other choice, domestic workers are forced to wear earplugs that are too large and sometimes cause discomfort because the wall of the ear canal is squeezed by excessively large earplugs. In consideration of comfort, manufacturer data related to earplug characteristics, such as material, weight, production methods, and ear pressure measurement must be referenced. Whether the size of the earplugs is suitable for workers must also be considered. If the wearing comfort of the earplugs can be increased, usage rates will also improve.

Because the external auditory canal (EAC) is a critical channel for sound reception (Oliveira, 1997), the effect of ageing on changes in the external shape of the ear canal is a frequently discussed topic (Sforza et al., 2009) in clinical practice. Shaw (1974) suggested that the human EAC wall can be categorized as two sections. The lateral 1/3 portion is comprised of cartilage, and the medial 2/3 portion near the eardrum is the bony structure. The average length of the adult ear canal is approximately 22.5 mm (Shaw, 1974). Shanks and Lilly (1981) stated in their publication "An evaluation of tympanometric estimates of ear canal volume study" that if tympanometry is employed to measure the ear canal volume, the human ear canal cross-sectional area must be presumed as a fixed value and the volume of the ear canal would not change as a result of variations in the soft tissue in the ear canal or changes in the eardrum (Shanks and Lilly, 1981). Zemplenyi et al. (1985) developed a novel approach that uses the optical method to measure the length between the opening of the ear canal and the eardrum (Zemplenyi et al., 1985). Egolf et al. (1993) used computer-aided tomography (CAT) to scan ear canals of cadavers to measure the volume of the external ear canal and compared the results with the those obtained using the injection measurement method, and observed a 6.12% difference between the two methods (Egolf et al., 1993). Shahnaz and Davies (2006) used tympanometry to measure tympanometric peak pressure and ear canal volume (ECV) and examine differences in the tympanum figure measurement values between Chinese people and Caucasians. The study included a total of 159 participants (303 ears) between the age of 18 and 34 years.

When the tympanometric examination is conducted at a frequency of 226 Hz, the ECV can be obtained according to the principle of energy reflectance (ER) (Shahnaz and Davies, 2006; Yu et al., 2012). Voss et al. (2008) developed a non-invasive acoustic reflection measurement method to measure the ears of nine cadavers to calculate the ECV and volume of the middle ear cavity by applying ER. The results indicated that the measuring position affected the obtained measurement values. The downward trend of the reflective level of the ear is at its most sensitive when the frequency is below 2000 Hz; however, it does not significantly affect the eardrum area. They also summarized that the ear canal measurement position, ear canal cross-sectional area, and middle ear cavity volume produced the three greatest variances (Voss et al., 2008). Al-Hussaini et al. (2011) investigated the tympanometric measurement accuracy of the external ECV, and used the Kamplex tympanometer to measure the ECV. The study shows that the ECV is approximately 1.4 $cm^3$, indicating that the Kamplex tympanometer is an accurate measurement tool for the ECV (Al-Hussaini et al., 2011). Yost (2000) stated that the length of the human ear canal is between approximately 2.3 and 2.97 cm.

The standards for earplug specification verification items vary among nations, and there is no standard size for earplugs. The ANSI S12.6 standards for U.S. hearing protection devices employ five plastic balls with different diameters: extra-small (7.26 mm), small (8.48 mm), medium (9.27 mm), large (10.46 mm), and extra-large (11.53 mm), to measure the ear canal diameter using the direct contact method. However, this standard does not specify any provision for differentiating earplug sizes. However, the content of earplug-related tests under the CNS national standard in Taiwan specify large, medium, and small sizes (CNS T2012 8454, 1982). However, because Taiwanese earplugs are often imported and these earplugs were designed based on foreign ear canal sizes, they occasionally do not match the ear canal size of Taiwanese people. When earplugs do not fit properly, users may feel discomfort and choose not to wear them on a long-term basis or may be unwilling to wear them.

Therefore, this study employs a non-contactable and non-invasive measurement method to measure the EAC size of Taiwanese workers, and provides a reference for earplug options and fittings. Preliminary planning of this study entailed researching the ear canal of the Taiwanese labor population, using a non-invasive method to measure the geometric shape of the ear canal. This study employs high-resolution computed tomography (HRCT) and medical imaging software for experiments to calculate the ear canal opening external shape and volume for Taiwanese workers. The participants of this study are 40 Taiwanese workers (20 men and 20 women).

## 2. Materials and methods

This study uses HRCT (TOSHIBA/Aquilionm, Tokyo, Japan) to obtain two-dimensional EAC images of the 20 men (average age: 25.5 y) and 20 women (average age: 24.67 y). Each CT image is composed of 512 × 512 pixels, with each pixel size set at $0.175 \times 0.175$ $mm^2$; slice thickness was 0.5 mm and voxel size was $0.175 \times 0.175 \times 0.5$ $mm^3$. The study uses Amira® imaging software 4.1(Visage Imaging, USA) to display images for the external ear area of the skull's temporal bone for a living person. The zoom and data window are used to adjust the minimum/maximum threshold values. The minimum and maximum are adjusted to the lowest and highest threshold values, respectively, to display the EAC image, which includes: (a) cavum conchae, (b) ear canal opening, (c) ear canal, and (d) eardrum (Fig. 1). The brush and magic wand functions

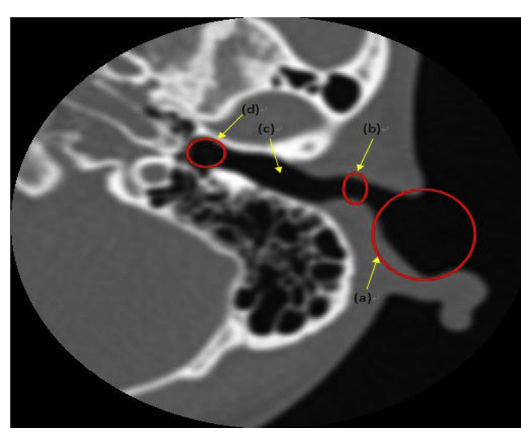


**Fig. 1.** Image of the external ear area of (a) cavum conchae, (b) ear canal opening, (c) ear canal, and (d) eardrum.