TECHNICAL SPECIFICATION

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Respiratory protective devices — Human factors —

Part 7: Hearing and speech

Appareils de protection respiratoire — Facteurs humains —

Partie 7: Discours et audition

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Foreword

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The committee responsible for this document is ISO/TC 94, *Personal safety — Protective clothing and equipment*, Subcommittee SC 15, *Respiratory protective devices*.

ISO/TS 16976 consists of the following parts, under the general title *Respiratory protective devices — Human factors*:

— *Part 1: Metabolic rates and respiratory flow rates*

— *Part 2: Anthropometrics*

— *Part 3: Physiological responses and limitations of oxygen and limitations of carbon dioxide in the breathing environment*

— *Part 4: Work of breathing and breathing resistance: Physiologically based limits*

— *Part 5: Thermal effects*

— *Part 7: Hearing and speech*

— *Part 8: Ergonomic factors*

The following part is under preparation:

— *Part 6: Psycho-physiological effects*

Introduction

For an appropriate design, selection and use of respiratory protective devices, basic physiological demands of the user must be considered. The function of a respiratory protective device, the way it is designed and used and the properties of its material may affect communications: either speech or hearing or both.

This part of ISO/TS 16976 belongs to a series of documents providing basic physiological and anthropometric data on humans. It contains information about hearing and speech associated with wearing respiratory protective devices.

Respiratory protective devices — Human factors —

Part 7:
Hearing and speech

1 Scope

This part of ISO/TS 16976 contains information related to the interaction between respiratory protective devices and the human body functions of hearing and speech.

2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 1999, *Acoustics — Estimation of noise-induced hearing loss*

ISO 16972, *Respiratory protective devices — Terms, definitions, graphical symbols and units of measurement*

3 Terms and definitions, and abbreviated terms

3.1 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 1999, ISO 16972 and the following apply.

3.1.1
hearing
manner in which the brain and central nervous system recognizes and interprets sounds

3.1.2
ototoxicity
damage to hearing from overexposure to drugs or toxic substances

3.1.3
noise
unwanted sound

3.1.4
presbycusis
gradual sensorineural hearing loss due to natural ageing

3.1.5
sound
form of energy that moves through media in waves of pressure

3.1.6
sound pressure
local pressure change caused by the vibration

Note 1 to entry: Measured in pascals (Pa).

3.2 Abbreviated terms

SPL sound pressure level

NIHL noise induced hearing loss

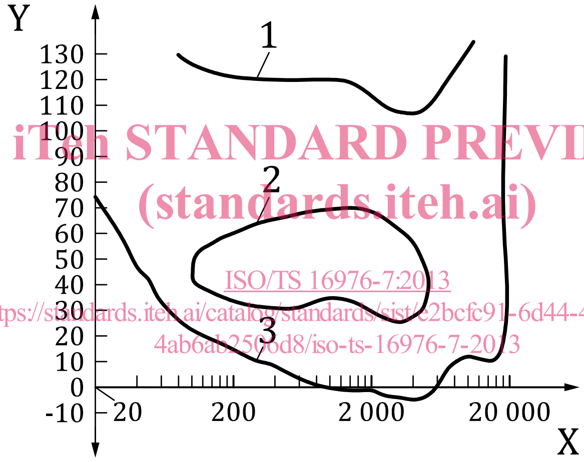
TWA time-weighted average

STI speech transmission index

SII speech intelligibility index

4 Range of hearing and speech

Humans with normal hearing can usually hear sound pressure waves in a frequency range of about 20 Hz to 20 000 Hz, but the ear is most sensitive to frequencies from 500 Hz to around 4 000 Hz and declines dramatically in sensitivity as frequencies drop below 500 Hz. Figure 1 depicts the frequencies response and sound pressure level response of human hearing and speech. The frequency range is affected by ageing as explained further in 7.3.



Key

X logarithmic sale of frequency (Hz)

Y sound pressure level (dB)

1 pain threshold

2 range of speech

3 hearing threshold

Figure 1 — Range of human hearing and speech

5 Measurement of sound pressure

Sound pressure is the local pressure change caused by the vibration and is measured in pascals (Pa). Sound pressure level (SPL) is the logarithmic ratio of the sound pressure to a reference pressure and is expressed in decibels (dB) by the equation

$$L_p = 20 \log_{10}\left(\frac{P_{\text{RMS}}}{P_0}\right)$$

where

L_p is the sound pressure level, in dB;

P_{RMS} is the root mean square (RMS) sound pressure, in Pa;

P_0 is the sound reference pressure, in Pa.

In air, the sound reference pressure is 0,000 02 Pa. That reference is based on the average human threshold of hearing at a frequency of 1 000 Hz.

When measuring sound pressure level as it relates to human perception, weighting factors are used to represent human threshold at different frequencies. The most common is the A-weighted sound measurement which approximates the human threshold at 40 dB and is expressed as dBA. Two other sound measuring weighting factors exist: B-weighted and C-weighted, which approximate the human threshold at 70 dB and 100 dB, respectively.

Examples of some typical sound levels are:

library	40 dBA
normal conversation	60 dBA
traffic noise	80 dBA
metal shop	100 dBA
siren	120 dBA
jet engine	140 dBA

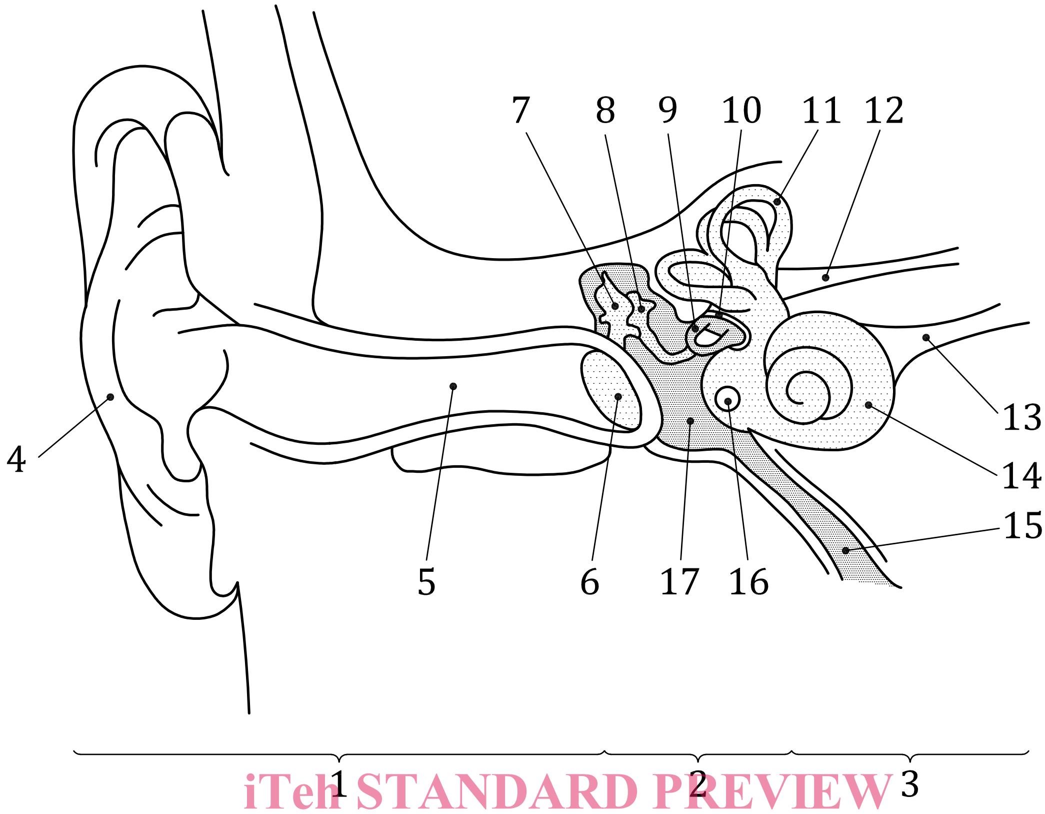
A perceived difference in sound level occurs at approximately 3 dB, and a perceived doubling of sound volume occurs with a 10 dB increase in sound pressure level.

6 Physiology of the ear

6.1 General

The human ear is the sense organ that detects sounds and changes the pressure waves into a signal of nerve impulses that is sent to the brain. The ear not only receives and converts sound but also plays a major role in the sense of balance and body position.

As shown in Figure 2, the ear is usually described in three sections: the outer ear (key 1), middle ear (key 2) and inner ear (key 3).



Key

1 outer ear
2 middle ear
3 inner ear
4 pinna
5 external auditory channel
6 tympanic membrane
7 malleus
8 incus
9 stapes
10 oval window
11 semicircular canals
12 vestibular nerve
13 cochlear nerve
14 cochlea
15 Eustachian tube
16 round window
17 tympanic cavity

Figure 2 — Physiological ear terms

6.2 Outer ear

The outer ear is the most external portion of the ear. The outer ear includes the pinna (also called auricle), the ear canal, and the very most superficial layer of the ear drum (also called the tympanic membrane). In humans, the only visible portion of the ear is the outer ear. The outer ear does help get sound (and imposes filtering), but the ear canal is very important. Unless the canal is open, hearing will be damped. Ear wax (cerumen) is produced by glands in the skin of the outer portion of the ear canal. The outer ear ends at the most superficial layer of the tympanic membrane. The tympanic membrane is commonly called the ear drum.

The pinna helps direct sound through the ear canal to the tympanic membrane (eardrum).

6.3 Middle ear

The middle ear, an air-filled cavity behind the ear drum (tympanic membrane), includes the three ear bones or ossicles: the malleus (or hammer), incus (or anvil), and stapes (or stirrup). The opening of the

Eustachian tube is also within the middle ear. The three bones are arranged so that movement of the tympanic membrane causes movement of the malleus, which causes movement of the incus, which causes movement of the stapes. When the stapes footplate pushes on the oval window, it causes movement of fluid within the cochlea (a portion of the inner ear).

In humans the middle ear (like the ear canal) is normally filled with air. Unlike the open ear canal, however, the air of the middle ear is not in direct contact with the atmosphere outside the body. The Eustachian tube connects from the chamber of the middle ear to the back of the pharynx.

The arrangement of the tympanic membrane and ossicles works to efficiently couple the sound from the opening of the ear canal to the cochlea. There are several simple mechanisms that combine to increase the sound pressure.

— The first is the "hydraulic principle". The surface area of the tympanic membrane is many times that of the stapes footplate. Sound energy strikes the tympanic membrane and is concentrated to the smaller footplate.

— A second mechanism is the "lever principle". The dimensions of the articulating ear ossicles lead to an increase in the force applied to the stapes footplate compared with that applied to the malleus.

— A third mechanism channels the sound pressure to one end of the cochlea, and protects the other end from being struck by sound waves. In humans, this is called "round window protection".

6.4 Inner ear

The inner ear includes both the organ of hearing (the cochlea) and a sense organ that is attuned to the effects of both gravity and motion (labyrinth or vestibular apparatus). The balance portion of the inner ear consists of three semicircular canals and the vestibule. When sound strikes the ear drum, the movement is transferred to the footplate of the stapes, which presses into one of the fluid-filled ducts of the cochlea. The fluid inside this duct is moved, flowing against the receptor cells of the Organ of Corti, which fire. These stimulate the spiral ganglion, which sends information through the auditory portion of the eighth cranial nerve to the brain.

7 Hearing loss

7.1 Conductive hearing loss

Abnormalities such as impacted ear wax (occlusion of the external ear canal), fixed or missing ossicles, or holes in the tympanic membrane generally produce conductive hearing loss. Conductive hearing loss may also result from middle ear inflammation causing fluid build-up in the normally air-filled space. In some cases conductive hearing loss is reversible.

7.2 Ototoxicity

A number of drugs in clinical use are considered "ototoxic", having the potential to cause damage to hearing as a side effect. Hearing loss caused by ototoxic drugs can be reversible or permanent.

7.3 Presbycusis

Hearing loss caused by natural aging affects the higher frequencies making word recognition difficult, see Clause 8. It is permanent.

7.4 Noise induced hearing loss (NIHL)

NIHL is caused by exposure to sound levels or durations that damage the hair cells of the cochlea. Initially, the noise exposure may cause a temporary threshold shift, that is, a decrease in hearing sensitivity that typically returns to its former level within a few minutes to a few hours. Repeated exposures lead to a permanent threshold shift, which is an irreversible sensorineural hearing loss. Hearing loss has causes

