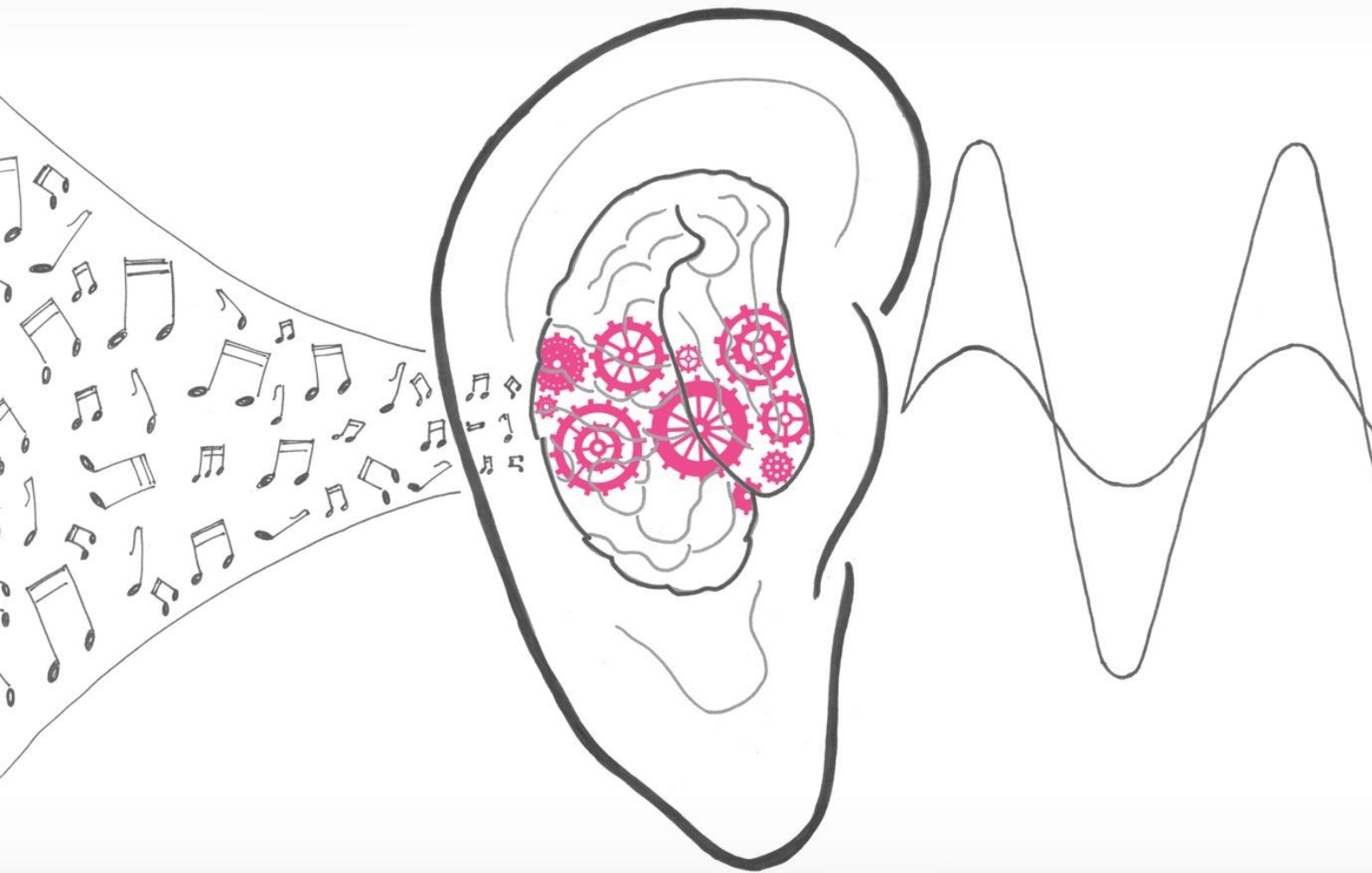




GHENT  
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# Prevalence and characteristics of hearing impairment and/or tinnitus caused by noise exposure in Flanders



Sofie Degeest  
2017





**UNIVERSITEIT  
GENT**

Faculty of Medicine and Health Sciences  
Department of Speech, Language and Hearing Sciences

**Prevalence and characteristics of hearing impairment  
and/or tinnitus caused by noise exposure in Flanders**

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*“Every mountain top is within reach if you just keep climbing.”*

*Barry Finlay*







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## LIST OF PUBLICATIONS

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This thesis is based on the following articles that were published, accepted for publication or submitted to international peer reviewed journals:

1. Degeest, S., Clays, E., Corthals, P., & Keppler, H. (2017). Epidemiology and risk factors for leisure noise-induced hearing damage in Flemish young adults. *Noise and Health*, 19(86), 10-19.
2. Degeest, S., Keppler, H., Corthals, P., Clays, E. (2017). Epidemiology and risk factors for tinnitus after leisure noise exposure in Flemish young adults. *International Journal of Audiology*, 56(2), 121-129.
3. Degeest, S., Corthals, P., Vinck, B., & Keppler, H. (2014). Prevalence and characteristics of tinnitus after leisure noise exposure in young adults. *Noise and Health*, 16(68), 26-33.
4. Degeest, S., Corthals, P., Dhooge, I., & Keppler, H. (2016). The impact of tinnitus characteristics and associated variables on tinnitus-related handicap. *The Journal of Laryngology & Otology*, 130(1), 25-31.
5. Degeest, S., Keppler, H., & Corthals, P. (2015). The effect of age on listening effort. *Journal of Speech, Language, and Hearing Research*, 58(5), 1592-1600.
6. Degeest, S., Keppler, H., & Corthals, P. (2016). The effect of tinnitus on listening effort in normal-hearing young adults: a preliminary study. *Journal of Speech, Language, and Hearing Research*, accepted for publication September 12, 2016.

## LIST OF ABBREVIATIONS

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ABR	Auditory Brainstem response
ANOVA	Analysis of Variance
BAHPHL	Beliefs About Hearing Protection and Hearing Loss
CAS	Contralateral Acoustic Stimulation
CG	Control Group
CI	Confidence Interval
dB	Decibel
dB A	Decibel A-weighted
dB HL	Decibel Hearing Level
dB SL	Decibel Sensation Level
dB SPL	Decibel Sound Pressure Level
DPOAE(s)	Distortion Product Otoacoustic Emission(s)
EEG	Electroencephalogram
ERP(s)	Event Related Potential(s)
ES	Efferent Suppression
HBM	Health Belief Model
HPD(s)	Hearing Protector Device(s)
Hz	Hertz
HQ	Hyperacusis Questionnaire
IHC(s)	Inner Hair Cells(s)
kHz	kilohertz
$L_{Aeq}$	Equivalent A-weighted Sound Level
LDL(s)	Loudness Discomfort Level(s)
MML(s)	Minimum Masking Level(s)

MOC	Medial Olivocochlear
mPa	Millipascal
n.a.	Not Applicable
NBN	Narrow Band Noise
NIHL	Noise-Induced Hearing Loss
NITS	Noise-Induced Threshold Shift
NIT	Noise-Induced Tinnitus
OAE(s)	Otoacoustic Emission(s)
OHC(s)	Outer Hair Cell(s)
OR	Odds Ratio
peSPL	peak equivalent Sound Pressure Level
PTA	Pure Tone Average
PMP(s)	Personal Music Player(s)
PTS	Permanent Threshold Shifts
RI	Residual Inhibition
SD	Standard Deviation
SNR	Signal-to-Noise Ratio
SPSS	Statistical Package for Social Sciences
TEOAE(s)	Transient Evoked Otoacoustic Emission(s)
TG	Tinnitus Group
THI	Tinnitus Handicap Inventory
TPB	Theory of Planned Behaviour
TSCHQ	Tinnitus Sample Case History Questionnaire
TTS	Temporary Threshold Shifts
WN	White Noise
YANS	Youth Attitude to Noise Scale

## SUMMARY

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Excessive noise levels are increasingly common in different aspects of daily life (World Health Organization, 2015). Although noise exposure is often thought of as an occupational hazard, there is growing concern about the risks of noise exposure during leisure activities, especially in teenagers and young adults. Excessive noise levels during leisure time can result in hearing damage and/or the development of hearing-related symptoms such as tinnitus, thereby leading to problems with communication and a decrease in the quality of life.

The main objective of this thesis was to determine and describe the effects of leisure noise exposure on the auditory system in Flemish young adults, with special attention to the presence and impact of tinnitus.

First, the prevalence of hearing damage and noise-induced tinnitus (NIT) was determined in 517 young Flemish adults between 18 and 30 years. We found that young adults participate in several leisure activities, with a wide variation in attendance and estimated noise levels per activity. Regarding the evaluation of their hearing status, no clinically significant hearing deteriorations were found among the young adults in this thesis. In contrast, the majority of young adults reported temporary tinnitus (68.5%) and even 6.4% already indicated chronic tinnitus due to leisure noise exposure. Moreover, the results indicated that increased levels of noise during leisure time increase the risk of chronic tinnitus and that once chronic tinnitus is present, it might serve as a trigger towards more awareness of the risks of noise and the importance of hearing protection devices (HPDs).

Second, the subjective characteristics of both temporary and chronic tinnitus after exposure to leisure noise were evaluated in 151 young Flemish adults between 18 and 30 years. Based on the results of a questionnaire, temporary and chronic tinnitus were found to have similar characteristics. Besides, in subjects suffering from chronic tinnitus, subclinical damage was demonstrated by measuring otoacoustic emissions (OAEs). Furthermore, the (psychoacoustic) characteristics of tinnitus and tinnitus-related variables were determined in subjects with chronic tinnitus in order to explore their relationship with tinnitus-related handicap. Based on the results of 81 adults between 18 and 73 years with chronic tinnitus,

tinnitus awareness during the day, and especially hyperacusis, were found to be related to tinnitus handicap.

Finally, a dual-task paradigm was used to measure listening effort. The effect of age on the amount of listening effort was examined in a general population of adults between 18 and 77 years. Results showed that, independent of hearing sensitivity, age is a significant determinant of listening effort, whereby listening effort increases with increasing age. Furthermore, the effect of tinnitus on listening effort was examined. Based on the results of 13 normal-hearing young adults between 18 and 31 years with chronic tinnitus and a matched control group, a significant increase in listening effort was found in the subjects with chronic tinnitus.

In conclusion, the results of this thesis underpin the importance of educating young adults about the risks of noise during leisure activities, with special attention to tinnitus as a sign of overexposure. In addition, assessing several variables associated with tinnitus would make it possible to identify patients at risk of increased tinnitus-related handicap. Finally, a test for listening effort can provide useful information complementary to the traditional audiological assessment procedures. Further research can focus on the optimization and implementation of this test in the assessment of tinnitus.



## SAMENVATTING

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Excessieve geluidsniveaus zijn alomtegenwoordig in verschillende aspecten van het dagelijkse leven (World Health Organization, 2015). Hoewel lawaai blootstelling meestal beschouwd wordt als een beroepsrisico, blijkt er een toenemende ongerustheid over de risico's van lawaai blootstelling tijdens vrijetijdsactiviteiten, voornamelijk bij tieners en jongvolwassenen. Excessieve lawaai blootstelling geeft aanleiding tot lawaaislechthorendheid of het ontwikkelen van lawaai geïnduceerde symptomen zoals tinnitus, welke op hun beurt kunnen leiden tot communicatieproblemen of een afname van de levenskwaliteit.

Het doel van dit doctoraatsonderzoek bestond erin om de effecten van lawaai blootstelling tijdens vrijetijdsactiviteiten op het auditief systeem bij Vlaamse jongvolwassenen te bepalen en te beschrijven. Hierbij werd voornamelijk gefocust op de aanwezigheid en de impact van tinnitus.

De prevalentie van gehoorschade en lawaai geïnduceerde tinnitus werd bepaald bij 517 Vlaamse jongvolwassenen tussen 18 en 30 jaar. We vonden dat jongeren regelmatig deelnemen aan diverse vrijetijdsactiviteiten, met een grote variatie in frequentie van deelname en geschatte intensiteitsniveaus per activiteit. Met betrekking tot de evaluatie van de gehoorstatus werd geen klinische gehoorsdaling gevonden bij de jongvolwassenen in dit onderzoek. In tegenstelling tot hun gehoorstatus rapporteert de meerderheid van de jongvolwassenen tijdelijke tinnitus (68.5%) en geeft 6.4% aan chronische tinnitus te ervaren als gevolg van lawaai blootstelling tijdens vrijetijdsactiviteiten. Bovendien bleek uit de resultaten dat excessieve geluidsniveaus tijdens vrijetijdsactiviteiten het risico op chronische tinnitus kunnen verhogen. Daarnaast bleek chronische tinnitus, van zodra aanwezig, een trigger die kan leiden tot een toenemend bewustzijn voor de risico's van lawaai en het belang van gehoorbescherming.

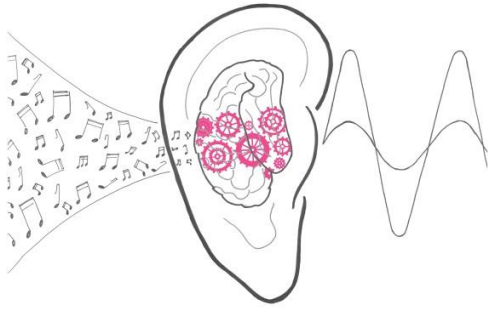
Vervolgens werden de subjectieve karakteristieken van zowel tijdelijke als chronische tinnitus na blootstelling aan lawaai in de vrije tijd geëvalueerd bij 151 Vlaamse jongvolwassenen tussen 18 en 30 jaar. Tijdelijke en chronische tinnitus bleken vergelijkbare karakteristieken te vertonen. Bovendien kon bij de jongeren met chronische tinnitus subklinische gehoorschade gedetecteerd worden aan de hand van otoakoestische emissies

(OAEs). Verder werden de (psychoakoestische) karakteristieken van tinnitus evenals variabelen geassocieerd met tinnitus bepaald bij personen met chronische tinnitus om de relatie met tinnitusgerelateerde handicap te evalueren. Op basis van de resultaten van 81 volwassenen tussen 18 en 73 jaar met chronische tinnitus bleek dat het bewustzijn van tinnitus gedurende de dag en de aanwezigheid van hyperacusis gerelateerd is aan tinnitus handicap.

Tot slot werd een dubbele taakparadigma gebruikt om de mate van luisterinspanning na te gaan. In de eerste plaats werd het effect van leeftijd op de mate van luisterinspanning geëvalueerd bij een algemene populatie van volwassenen tussen 18 en 77 jaar. Resultaten toonden aan dat leeftijd, onafhankelijk van gehoorstatus, een belangrijke voorspeller is voor de mate van luisterinspanning. Luisterinspanning bleek significant toe te nemen met toenemende leeftijd. Daarnaast werd het effect van tinnitus op luisterinspanning onderzocht. Op basis van de resultaten van 13 normaalhorende jongvolwassenen tussen 18 en 31 jaar met chronische tinnitus en een controlegroep werd een significante toename van luisterinspanning aangetoond bij personen met chronische tinnitus.

De resultaten van dit onderzoek tonen aan dat het belangrijk blijft om jongeren te informeren en sensibiliseren omtrent de risico's van lawaai tijdens vrijetijdsactiviteiten, waarbij speciale aandacht kan geschonken worden aan tinnitus als lawaaigeïnduceerd symptoom. Bovendien blijkt dat de evaluatie van verschillende factoren geassocieerd met tinnitus het mogelijk maakt om patiënten met een verhoogd risico op tinnitusgerelateerde handicap te identificeren. Ten slotte blijkt dat een test voor luisterinspanning nuttige informatie kan leveren naast de informatie verkregen uit de bestaande audiologische testprocedures. Verder onderzoek kan zich bijgevolg richten op het optimaliseren van deze test bij de beoordeling van tinnitus.





# **GENERAL INTRODUCTION**



---

Auditory perception is the ability to perceive and understand sounds through the organ of hearing. Hearing impairment occurs when there is damage to one or more parts of the auditory pathway. Especially exposure to excessive noise is one of the major causes of acquired hearing disorders (Rabinowitz, 2000).

Excessive noise levels are increasingly common in different aspects of daily life (World Health Organization, 2015). Although noise exposure is often thought of as an occupational hazard, there is growing concern about the risks of noise exposure during leisure activities, especially in teenagers and young adults.

Since the 1960s, several studies have investigated the possible effects of noise exposure from leisure activities on hearing (e.g. Lipscomb, 1969). In recent years, there is an increased access to and availability of noise sources during leisure time such as loud music through the use of personal music players (PMPs). Not surprisingly, leisure noise has been identified as a potential source of excessive noise that may contribute to hearing damage over time (e.g. Morata, 2007; Serra et al., 2005; Vogel, Brug, Van der Ploeg, & Raat, 2010), which makes it important to identify young people at risk for noise-induced hearing damage.

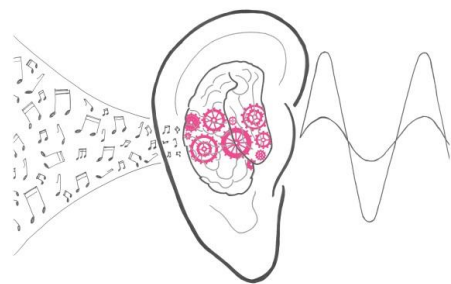
In addition to the identification of young people at risk for acquiring hearing damage, it is important to effectively investigate their hearing function in order to assess changes in hearing sensitivity as well as to assess the presence of other noise-induced symptoms. Especially tinnitus appears to be one of the most common reported symptoms after exposure to noise (Han, Lee, Kim, Lim, & Shin, 2009).

When hearing loss and/or tinnitus are present, it can affect the quality of life (Daniel, 2007; Henry, Dennis, & Schechter, 2005), making it important to identify subjects in need for intervention. Furthermore, common complaints associated with noise-induced hearing loss (NIHL) concern difficulties and increased effort during speech understanding. For decades, research stated that besides the peripheral hearing function, non-auditory central aspects, such as working memory, processing speed and selective attention, are likely to influence hearing and especially speech understanding in various listening situations (Akeroyd, 2008; Pichora-Fuller, Schneider, & Daneman, 1995). In addition to the known risks of noise exposure on hearing, there is growing evidence that especially tinnitus can affect some central cognitive processes that are involved in the process of listening and comprehending

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(e.g. Andersson & McKenna, 2006; Kujala & Brattico, 2009; Kujala et al., 2004). Therefore, a test for measuring listening effort may provide additional information above and beyond the traditional audiological measurements.

In this introduction, the **first chapter** provides an overview of the anatomy and physiology of the auditory system in order to highlight the distinct layers of the auditory system that will be investigated throughout the thesis. In the **second chapter**, the definition and classification of various noise sources will shortly be outlined. Moreover, a literature overview will be provided regarding leisure noise exposure and risk-taking behaviour among young people. The **third chapter** will describe the potential effects of noise on hearing as well as the prevalence of the most common noise-induced symptoms and their potential impact on the quality of life. Furthermore, the different audiological assessment techniques that can be used in the early detection of hearing damage and noise-induced symptoms will be outlined, each with their advantages and disadvantages. In addition, an introduction to a test for evaluating difficulties and effort related to speech understanding will be presented. Finally, the **fourth chapter** will describe the research goals of the present thesis.



# CHAPTER 1

## Anatomy and physiology of the auditory system





## 1.1 The peripheral auditory system

The human auditory system is responsible for the sense of hearing and is generally divided into the peripheral and central auditory system (Figure 1.1). The peripheral auditory system further consists of the outer ear, middle ear and inner ear, each having a key function in order to transfer sound waves from the environment to the auditory nerve.

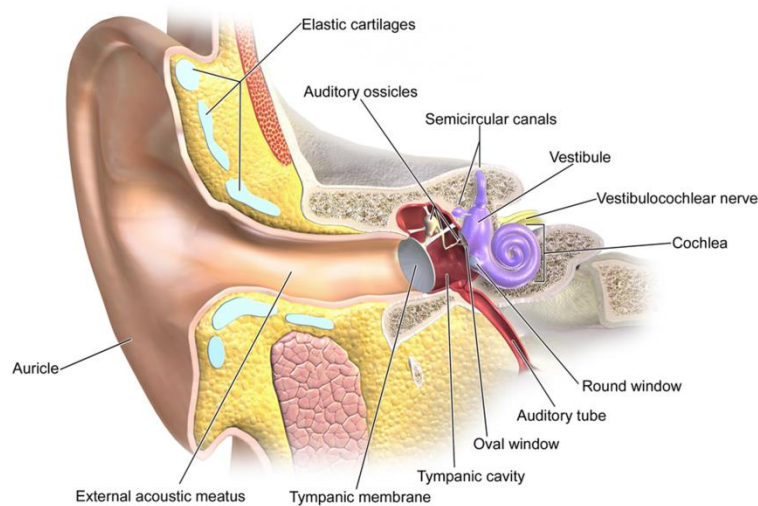


Figure 1.1 Anatomy of the human ear. (By Blausen.com staff. "Blausen gallery 2014". Wikiversity Journal of Medicine. DOI:10.15347/wjm/2014.010. ISSN 20018762.)

The process of hearing begins in the outer ear, which collects sound energy and directs it through the ear canal to the tympanic membrane. The incoming waves of sound energy cause vibration of the ossicular chain in the middle ear; a structure which comprises the malleus, incus and stapes. Movement of the stapes footplate in the oval window transforms the sound vibration into a fluid vibration inside the inner ear. The inner ear is embedded in the temporal bone and includes the vestibular and auditory organs. The auditory organ, or cochlea, is a spiraled tube divided into the scala tympani, scala vestibuli, and scala media. The scala media, or cochlear duct, is filled with endolymph, and contains the sensory organ necessary for hearing, i.e. the organ of Corti. The latter consists of one row of inner hair cells (IHCs) and three rows of outer hair cells (OHCs) as well as a complex of associated supporting cells and structures. Each hair cell has stereocilia at the apical pole of the cell that are embedded in the cuticular plate. The stereocilia of the OHCs are in direct contact with the tectorial membrane, while the stereocilia of the IHCs are not directly connected to this

membrane. The motion of the basilar membrane and the overlying tectorial membrane leads to a deflection of the hair cell stereocilia bundles. When the stereocilia move towards the longest stereocilium, transduction channels are opened, allowing ions to flow into the hair cells and produces depolarization. This process releases neurotransmitter at the presynaptic base of the hair cell, such that action potentials are initiated towards the afferent auditory nerve fibers (Hall, 2000a; Salvi, McFadden, & Wang, 2000). The OHCs function as the key elements for mechanical amplification of the basilar membrane vibrations (Zheng, Madison, Oliver, Fakler, & Dallos, 2002), which is necessary to enhance the sensitivity and frequency selectivity of hearing at low-intensity levels (Gold, 1948).

At various levels in the auditory pathway, neurons are tonotopically organized. Tonotopy arises from mechanical properties of the cochlea, such that different regions of the basilar membrane in the organ of Corti are stimulated by different frequencies. High frequency sounds cause maximum excitation at the basal turn, whereas low frequency sounds cause maximum excitation at the apical part of the cochlea. The tonotopic organization is preserved in the cochlear nerve, as each of the afferent nerve fibers correspond with a specific location in the cochlea (May, 2000).

## **1.2 The central auditory system**

Neural signals are directed along the eighth cranial nerve into the brainstem and eventually to various brain structures (Figure 1.2). First, the signals are directed to the dorsal and ventral divisions of the cochlear nucleus, where the processing of acoustic information begins. Cells of the dorsal divisions of the cochlear nucleus travel along the lateral lemniscus to the inferior colliculus in the mid-brain. Neurons of the ventral division of the cochlear nucleus target to the ipsilateral and contralateral superior olivary complex through the trapezoid body and from there to the nuclei of the lateral lemniscus and the inferior colliculus (Musiek & Oxholm, 2000).

Two different ascending pathways going from the cochlear nucleus to the cerebral auditory cortices can be distinguished (Møller, 2011a). These pathways are known as the classical or lemniscal pathways and the non-classical or extralemniscal pathways, whereby the main differences between those pathways are located in the thalamus.

The classical pathways are mainly crossed, even though with strong connections between the inferior colliculus. The neural information from the inferior colliculus is projected into the ventral part of the thalamic auditory nucleus, referred as the medial geniculate body, and further radiated to the primary auditory cortex. From the primary auditory cortex, there are connections to other parts of the cortex, including the secondary cortex (Møller, 2011a). The tonotopic organization found in the cochlea and auditory nerve fibers is maintained at the classical pathways, as it was demonstrated that all nuclei of the ascending auditory pathways display frequency selectivity (Møller, 2011a).

The non-classical pathways are connected with the medial and dorsal parts of the medial geniculate body. From there, cells directly project to the secondary auditory cortex and association cortices, thus bypassing the primary auditory cortex (Møller, 2011a). Association areas, located in the frontal, parietal, temporal and occipital areas of the brain, are involved in among others the integration of information of different sensory systems, planning, attention and memory (Musiek & Oxholm, 2000; Yeo et al., 2011). Furthermore, the non-classical pathways provide a subcortical route to the emotional brain through the connection with the amygdala, which is part of the limbic system (Møller, 2011a). The physiology of the non-classical pathways is not well known and studies investigating its physiology are scarce. It seems, however, that compared to the classical pathways a less distinct and broader tuning can be found in neurons of the non-classical pathways (Møller, 2011a).

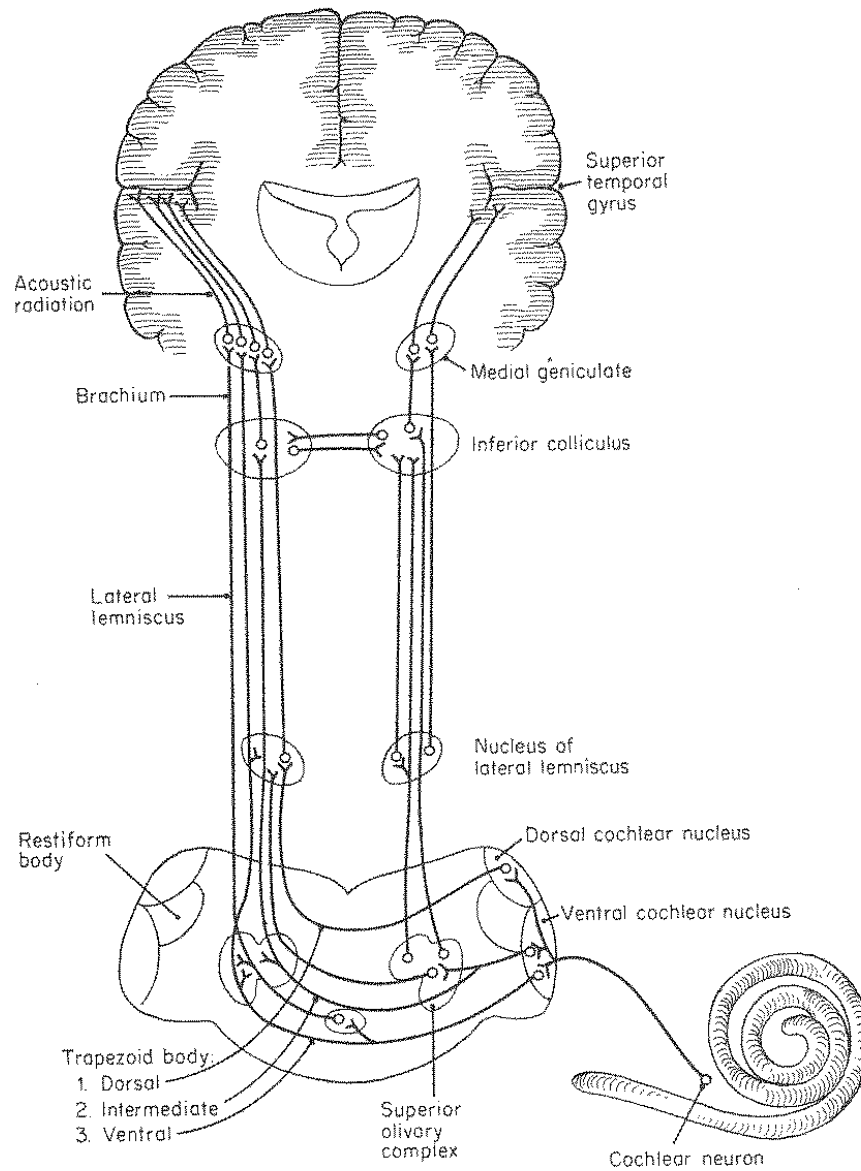
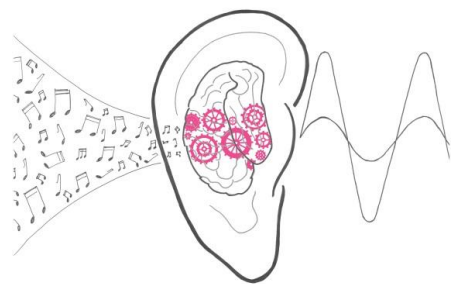


Figure 1.2 The central auditory pathways. (From: *Dizziness, Hearing Loss and Tinnitus*, by Baloh R., 1998, p. 48. With permission from Oxford University Press.)



## CHAPTER 2

### Noise exposure during leisure time



## **2.1 Noise: definition and classification**

In general, noise is defined as an unwanted sound (Berglund, Lindvall, & Schwela, 2000) and has become a widespread public problem. There are several sources of noise to which people are exposed, which are mostly classified as either occupational or environmental noise. Occupational noise refers to noise at the workplace, while environmental noise includes noise in a variety of non-occupational settings such as transport, traffic and leisure activities (Fritschi, Brown, Kim, Schwela, & Kephelopoulos, 2011).

In recent years, there is a growing concern about the ever-greater exposure to noise during leisure time, especially in teenagers and young adults.

## **2.2 Leisure noise exposure in young people**

Leisure noise exposure can be categorized into loud music or noise during participation in non-musical activities. Loud music exposure can arise from various sources such as live concerts, discotheques or night clubs on the one hand and PMPs or various musical instruments on the other hand (Beach, Williams, & Gilliver, 2013; Jokitulppo, 2003; Jokitulppo, Björk, & Akaan-Penttilä, 1997; Jokitulppo, Toivonen, & Björk, 2006; Meyer-Bisch, 1996; Serra et al., 2005; Smith, Davis, Ferguson, & Lutman, 2000). Non-musical activities mostly comprise attending sport events, watching movies, going to the theatre, using noisy tools or shooting firearms (Biassoni et al., 2005; Jokitulppo, 2003; Jokitulppo et al., 1997; Jokitulppo et al., 2006).

Several studies on the type of leisure noise exposure among young people were conducted in various countries. Smith et al. (2000) investigated the prevalence and type of social noise exposure in English young adults (18-25 years). Significant noise exposure in nightclubs was found in 11%, from Hi-fis in 3%, from PMPs in 2% and during attendance at live concerts in 0.6% of the young adults. In Finnish adults (25-58 years), the majority was exposed to noise from home stereos (58%), while also 34% went to nightclubs/pubs and 9% used PMPs (Jokitulppo, 2003). Another study in Argentine adolescents (14-17 years) showed that attendance at discotheques was the most favorable musical activity, followed by attendance at live concerts and listening to PMPs (Serra et al., 2005). Beach, Williams, et al. (2013) examined the risk of hearing damage from leisure noise in young Australian adults (18-35



years). The major contributor to noise exposure was nightclub attendance (70%), followed by live concerts or attending sporting events (Beach, Williams, et al., 2013). A worldwide investigation of the World Health Organization (2015) revealed that about 50% of the teenagers and young adults (12-35 years) in middle- and high-income countries are exposed to excessive noise levels from PMPs and approximately 40% is exposed to high noise levels at nightclubs, discotheques and bars.

Participation in noisy non-musical activities is also reported by young adults, though less common than musical activities (Biassoni et al., 2005). Watching movies or going to the theater (26%) and using noisy tools at home (19%) were reported to be the most frequent non-musical activities (Jokitulppo, 2003). Attendance at sports events is also relatively common among young adults. It was found that 54% of Australian 18- to 35-year-olds attend a sporting event at least once per year (Beach, Williams, et al., 2013).

Hence, it is clear from literature that young people are mainly exposed to noise at nightclubs and discotheques, though also PMPs have become increasingly popular over the last two decades. Technological developments in the realm of PMPs has rapidly increased their availability among young people (Scientific Committee on Emerging and Newly Identified Health Risks (SCENIHR), 2008; Vogel, van de Looij-Jansen, Mieloo, Burdorf, & de Waart, 2012). Because PMPs are more compact and have larger storage and battery capacity, they can be used more easily in various situations and for a longer period of time (Fligor & Cox, 2004; Zhao, Manchaiah, French, & Price, 2010). The output levels of PMPs can reach up to 103 dBA (Keppler, Dhooge, Maes, et al., 2010), with average volume levels exceeding 85 dBA (Torre III, 2008; Trask, Abkas, & Jous, 2006; Williams, 2005). On the other hand, the sound levels at nightclubs and discotheques were reported to be even higher. In nightclubs, the mean sound levels can range from 85 to 105 dBA (Smith et al., 2000). Besides, Serra et al. (2005) reported equivalent noise levels up to 112 dBA for discotheques.

Hence, the increased availability of PMPs and the regular participation of young adults in several musical or noisy non-musical activities during leisure time are considered to be potentially harmful (e.g. Beach, Gilliver, & Williams, 2013; Keppler, Dhooge, Maes, et al., 2010; Meyer-Bisch, 1996). Specifically, the World Health Organization (2015) recently

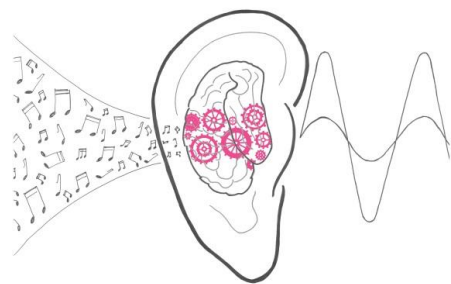
addressed that, due to unsafe listening practices, 1.1 billion young people worldwide could be at risk for hearing damage.

### **2.3 Risk-taking behaviour among young people**

Based on the Scientific Committee on Emerging and Newly Identified Health Risks (SCENIHR) (2008) the following statement was formulated: *“People who choose to listen to music or use personal music players can be exposed to loud sounds, which they do not consider as noise. An involuntary bystander may nevertheless be distracted and annoyed and may rightfully, call noise what is sound in his neighbour’s ears”.*

In Western Countries, most of the noise exposure among young people is related to voluntary participation in musical activities (Daniel, 2007). Since exposure to noise during leisure time may pose risks to hearing, participation in activities where loud music is played can be considered as risk-taking behaviour (Widén, 2013). However, many young people do not perceive loud music as risky (Daniel, 2007; Widén, 2013). Gilles, Thuy, De Rycke, and Van de Heyning (2014) evaluated the appreciation of sound levels at music events in 41 young adults (mean age 19.2 years). Approximately 70% of the respondents found the sound levels at discotheques satisfactory and 86% considered 98 dBA  $L_{Aeq,60min}$  as a desirable intensity level during a party (Gilles et al., 2014). Beach, Gilliver, et al. (2013) found that young adults who participate frequently in one type of noisy activity are more likely to participate in other noisy activities. According to Bohlin, Sorbring, and Erlandsson (2010), the decision to participate in an activity is based on pro-risk attitudes, which means that subjects with more pro-noise attitudes are more likely to participate in risky activities and will be less likely to undertake preventive actions such as wearing hearing protector devices (HPDs). Therefore, evaluating young people’s risk-taking behaviour and their attitude towards noise and HPDs in relation to leisure time activities is necessary in order to prevent (future) hearing problems (Widén, 2013).





## CHAPTER 3

**The effects of noise on the auditory system  
and its assessment techniques**



### **3.1 The effects of noise on hearing**

Exposure to noise can cause auditory effects, which pertain to discomfort in the ears or hearing-related symptoms (Basner et al., 2014). A number of studies have shown that excessive noise levels during leisure time can result in NIHL and/or the development of hearing-related symptoms such as tinnitus (Beach, Gilliver, et al., 2013; Davis, Lovell, Smith, & Ferguson, 1998; Fligor & Cox, 2004; Holgers & Pettersson, 2005; Jokitulppo, 2003; Jokitulppo et al., 1997). Such symptoms can affect the quality of life among others as a result of impaired conversation and communication (Davis & El Refaie, 2000; Sliwinska-Kowalska & Davis, 2012). In addition to the auditory effects of noise exposure, non-auditory effects are also reported and can include stress, psychological problems, cardiovascular abnormalities and decreased daily functioning (Passchier-Vermeer & Passchier, 2000).

The current chapter will describe the most common auditory noise-induced symptoms including their prevalence among young people and their potential associated influence on the quality of life. In addition, an overview of the current audiological assessment techniques for detecting those symptoms will be provided.

### **3.2 Noise-induced symptoms**

#### **3.2.1 Noise-induced hearing loss**

It is well-known that excessive noise exposure can lead to a reduction of hearing sensitivity, also defined as NIHL (American College of Occupational and Environmental Medicine, 2002). Specifically, exposure to excessive noise levels can induce alterations in the structural elements of the organ of Corti through metabolic and/or mechanical changes (Talaska & Schacht, 2007). Metabolic changes includes toxic reactions, which can induce cell death. On the other hand, mechanical changes result in direct physical disruption of the hair cells and surrounding cells (Talaska & Schacht, 2007).

Immediately after noise exposure, temporary threshold shifts (TTS) can occur due to structural changes including buckling of the pillar bodies and uncoupling of the OHC stereocilia from the tectorial membrane (Nordmann, Bohne, & Harding, 2000). Regular or prolonged noise exposure can eventually results in permanent threshold shifts (PTS). PTS are suggested to be generated by separate mechanisms than TTS (Nordmann et al., 2000).

Moreover, it seems that the development of PTS cannot be predicted from the magnitude of TTS (Melnick, 1991; Nordmann et al., 2000). Changes occurring with PTS include focal losses of hair cells and corresponding nerve fiber degeneration (Nordmann et al., 2000).

NIHL typically is a symmetric sensorineural hearing deficit in the high frequency region between 3.0 and 6.0 kHz (Rabinowitz, 2000; Serra et al., 2005). Continued exposure to excessive noise levels will result in a gradual deterioration of the hearing thresholds including the emergence of damage in other frequency regions (Clark & Bohne, 1999; Rabinowitz, 2000; Sliwinska-Kowalska & Davis, 2012). Therefore, in the initial stage, NIHL remains unnoticed since information from the frequency region below 3.0-to-6.0 kHz can efficaciously underpin speech perception in quiet (Daniel, 2007; Glasberg & Moore, 1989; Smoorenburg, 1992). However, the first symptom which is typically reported in the earlier stages includes difficulties with speech understanding in background noise. In this respect, NIHL can have a significant negative impact on a person's ability to communicate, which may cause a severe social effect (Basner et al., 2014). Furthermore, hyperacusis can emerge as a result of damage sustained to the inner ear. However, the specific generation mechanisms for hyperacusis are not mutually exclusive (Baguley, 2003) and can be related to either a peripheral source or hyperactivity of the central auditory pathways (Herráiz & Diges, 2011). In the literature, several terms such as noise sensitivity, audiosensitivity or reduced tolerance to noise have been used to describe hyperacusis (Katzenell & Segal, 2001), though often without a clear definition (Baguley & Andersson, 2007). Hence, Baguley and Andersson (2007) proposed to describe hyperacusis using a physiological and psychological component: *"The experience of inordinate loudness of sound that most people tolerate well, associated with a component of distress"* (p. 7).

For years, many studies have focused on the prevalence of NIHL among young people, though results vary between different studies. Some studies reported an increase in the prevalence of NIHL in both teenagers and young adults (Montgomery & Fujikawa, 1992; Shargorodsky, Curhan, & Farwell, 2010), while others could not find such results (Henderson, Testa, & Hartnick, 2011; Persson, Svedberg, & Göthe, 1993; Rabinowitz, Slade, Galusha, Dixon-Ernst, & Cullen, 2006). Besides, there is a large body of literature regarding the relation between hearing loss and leisure noise exposure, which has been summarized in a review article of Carter, Williams, Black, and Bundy (2014). These authors concluded that, so

far, the literature is not conclusive concerning the possible effects of leisure noise on hearing and further research concerning these possible effects is needed.

### **3.2.2 Tinnitus**

Tinnitus can be defined as the perception of sound in the absence of an external physical source (Møller, 2011c) and is mostly classified as either objective or subjective tinnitus (Møller, 2011b). Objective tinnitus can be detected by the patient as well as by other people and is usually caused by actual sounds generated in the body, such as myoclonus or vascular deficits. Subjective tinnitus is the most common form of tinnitus and is audible for the patient only. The present thesis focused on subjective tinnitus and will from now on be referred to as “tinnitus”.

Although tinnitus may result from many underlying pathologies, excessive noise exposure is considered as one of the most prevalent causes (Axelsson & Sandh, 1985; Henry, Dennis, et al., 2005). It has been suggested that noise-induced tinnitus (NIT) is triggered by cochlear injury, whereby deprivation of input to the nervous system results in changes of the central auditory system (Kaltenbach & Manz, 2011; Møller, 2011d). Specifically, cochlear deafferentation results in increased spontaneous neuronal activity along the auditory pathway (Eggermont & Roberts, 2004; Elgoyhen, Langguth, De Ridder, & Vanneste, 2015), which is reflected by an increase in neuronal excitation and a decrease in inhibition due to alterations in neurotransmission of GABA, glycine and glutamate (Llano, Turner, & Caspary, 2012). According to the homeostatic plasticity model, neuronal excitation is increased to compensate for a decrease in neuronal inhibition, which in turn maintains a stable mean firing rate. This increased excitation may therefore amplify neural noise, resulting in the perception of tinnitus. Furthermore, abnormal input such as excessive noise exposure may also activate neural plasticity (Møller, 2011d), according to evidence from animal studies that excessive noise levels can affect other structures than the cochlea, such as the cochlear nucleus (Morest, Ard, & Yurgelun-Todd, 1979). As a consequence of the increased spontaneous firing rate and neuronal synchronous activity along the auditory pathway, a reorganization of the tonotopic map occurs, so that cortical neurons respond to adjacent frequencies (Rauschecker, 1999). Hence, tinnitus can be perceived because of an over-representation of neuronal activity at the transition region from normal to impaired hearing



in the auditory cortex (Gerken, 1996). However, in patients with normal hearing to mild hearing loss it was found that tonotopic reorganization is not necessarily related with the perception of tinnitus (Langers, de Kleine, & van Dijk, 2012).

NIT can either be temporary or chronic tinnitus (Kaltenbach & Manz, 2011). Temporary tinnitus can often be noticed immediately after exposure to noise (Loeb & Smith, 1967) and usually does not last longer than a few seconds to a maximum of a couple of days, while chronic tinnitus lasts from months to years (Kaltenbach & Manz, 2011). While it has been suggested that transient NIT is more of peripheral origin, the involvement of more central aspects in chronic NIT are proposed (Kaltenbach and Manz, 2011). Most patients who have a long history of noise exposure complain of tinnitus that has a high-pitched tonal quality (Axelsson & Sandh, 1985; Chermak & Dengerink, 1987; Nageris, Attias, & Raveh, 2010). Although NIT has mostly been related to occupational noise, previous research also demonstrated an association between leisure noise exposure and tinnitus (Davis et al., 1998; Figueiredo et al., 2011). The prevalence of NIT among young people has been estimated in several researches conducted in different countries. In general, the prevalence of temporary tinnitus varies between 58% and 75% in young adults (Jokitulppo, 2003; Jokitulppo et al., 2006; Rosanowski, Eysholdt, & Hoppe, 2006). Chronic tinnitus is less prevalent than temporary tinnitus with a prevalence ranging between 5% and 10% among this group of age (Jokitulppo et al., 2006; Rosanowski et al., 2006). In Flanders, there are known prevalence rates for temporary and chronic tinnitus in a large group (~3892) of teenagers between 14 and 18 years and a group of university students between 19 and 26 years (Gilles et al., 2012; Gilles, Van Hal, De Ridder, Wouters, & Van de Heyning, 2013). Temporary tinnitus was reported by respectively 74.9% and 89.5% of the teenagers and university students, while the prevalence of chronic tinnitus ranged between 15% and 18% in both groups. However, prevalence data of NIT in a general group of Flemish young adults under 30 years of age are lacking. Since it is well known that young adults regularly participate in leisure activities (Beach, Williams, et al., 2013), research is necessary to explore the risks of acquiring tinnitus among this specific cohort of young adults in Flanders.

As it was described in the section regarding NIHL, the sensory hair cells in the organ of Corti are one of the most vulnerable structures as it comes to noise exposure, leading to cochlear injury (e.g. Talaska & Schacht, 2007). However, the fact that tinnitus does not occur in all

patients with hair cell injury and can be present in case of normal hearing indicates that more than one factor must be present for tinnitus to manifest (Møller, 2011d). According to Jastreboff and Hazell (2004), tinnitus has three major components: (1) auditory, (2) attentional, and (3) emotional. Initially, tinnitus is an auditory perception without a clinical significance. However, when the sound captures a person's awareness (i.e. attentional component), it can become problematic as the subject will actually listen to the tinnitus sound. When the subject begins to focus on the presence of tinnitus and undesirable emotional reactions occur, tinnitus will become a clinical problem leading to annoyance, frustration, depression, anxiety, etc. (Kaltenbach & Manz, 2011). In this respect, it has been assumed that the auditory perception of tinnitus is related to abnormal neuronal activity in the auditory pathways, while tinnitus distress is related to the co-activation of the non-auditory pathways, such as the frontal, limbic, memory and autonomic brain areas (Elgoyhen, Langguth, De Ridder, & Vanneste, 2015; Møller, 2011d).

The involvement of several components for tinnitus to be problematic is also evident from prevalence studies showing that when chronic tinnitus is experienced, most people can cope with this symptom, but for 1-to 2% of the population, it is a severe handicap that can substantially impair the quality of life (Axelsson & Ringdahl, 1989; Baigi, Oden, Almlid-Larsen, Barrenäs, & Holgers, 2011). Moreover, tinnitus is also found to be a more debilitating symptom than hearing loss (Axelsson & Prasher, 1999). Although the effects of tinnitus on quality of life are highly individualized, common reported problems are related to sleep, emotional well-being and hearing (Axelsson & Prasher, 2000; Fioretti, Fusetti, & Eibenstein, 2013; Martines, Bentivegna, Martines, Sciacca, & Martinciglio, 2010; Tyler & Baker, 1983; Tyler et al., 2006). However, it is difficult to early identify individuals who may develop problems due to their tinnitus to such a degree that it may negatively impair the quality of life (Hoekstra, Wesdorp, & van Zanten, 2014). Many studies have tried to identify factors that may be inherent to tinnitus severity (e.g. Henry, Dennis, et al., 2005; Tyler & Erlandsson, 2003), but there is still no consensus about the specific factors that may be involved when tinnitus severely affects the quality of life. Knowledge about factors that are associated with tinnitus severity would therefore be useful for clinicians in order to identify individuals who may develop problems.

Furthermore, a recent dimension in the field of tinnitus hypothesized that it may impair cognitive processing (Andersson & McKenna, 2006; McKenna & Hallam, 1999), as it has been repeatedly mentioned that tinnitus patients often indicated concentration difficulties (Andersson, Lyttkens, & Larsen, 1999; Hallam, McKenna, & Shurlock, 2004; Tyler & Baker, 1983). For example, tinnitus patients often indicate difficulties to maintain their concentration since a lot of effort and attention is directed to the tinnitus. Moreover, concentration difficulties indicated by tinnitus patients have been related to hearing difficulties, such as speech understanding in several listening situations (Andersson, Khakpoor, & Lyttkens, 2002; Tyler & Baker, 1983). In recent years, studies using brain imaging have shown that the central non-auditory areas are not only relevant when it comes to tinnitus distress, but, like the auditory regions, are also involved in the perception of tinnitus (Rauschecker, Leaver, & Mühlau, 2010). The auditory and non-auditory brain regions that seem to be involved in tinnitus are among others the dorsolateral prefrontal cortex, cingulate cortex, parietal cortex, temporoparietal junction, parahippocampus, amygdala and insula (for a review of the importance of these structures see Elgoyhen et al. (2015)). Tinnitus can thus be considered a complex symptom that involves alterations in the brain areas related to perception and distress, but also brain areas mediating memory and attention (De Ridder, Elgoyhen, Romo, & Langguth, 2011). Hence, tinnitus may impair cognitive processing, and more specific aspects related to attention or memory (e.g. Hallam, McKenna, & Shurlock, 2004; Andersson, Khakpoor, & Lyttkens, 2002). In the current tinnitus assessment procedures, however, there is no standard technique for the evaluation of the complaints associated with concentration available yet.

In conclusion, tinnitus is a multifactorial symptom which will require a careful selection of treatment options. Several treatments or therapies for tinnitus have been proposed based on the underlying pathophysiology as well as the awareness of tinnitus and the distress a subject can experience (Goodey, 2011). When hearing loss is present, treatment can focus on normalizing the sensory input by using, for example, hearing aids or cochlear implants. Furthermore, sensory input can be manipulated by, for example, auditory training, sound stimulation or music treatment. Emotional factors associated with tinnitus are often addressed through counselling and cognitive behavioural treatment, but also through sound stimulation or music treatment. In addition also direct approaches to the central nervous

system exist, for example by pharmacological treatments or neuro-modulation. For a review of the possible treatments for tinnitus, see Kleinjung (2011). Although the treatment options are an important aspect to consider in the evaluation process of tinnitus patients, the present thesis will focus on the assessment of tinnitus.

### **3.3 Audiological evaluation of noise-induced damage**

Given the above mentioned findings, it is important to identify several noise-induced symptoms together with their potential impact on the ability to understand speech and the quality of life. The currently available audiological assessment methods for detecting noise-induced damage, each with their advantages and disadvantages, will be discussed in the following paragraphs.

#### **3.3.1 Questionnaires**

In general, the majority of research uses questionnaires. Questionnaires have the advantage to be relatively inexpensive and most of them can be completed easily and quickly (Milne, 1999). Furthermore, questionnaires enable a larger study sample and more statistical power and they can be used easily in combination with other assessment methods (Nieuwenhuijsen, 2005). Especially for tinnitus, questionnaires are suitable (e.g. to evaluate the characteristics of tinnitus) as this symptom is mostly subjective and cannot be heard by the examiner. Also, the impact of noise-induced symptoms on daily functioning and the quality of life can be evaluated through questionnaires.

However, hearing loss determined through questionnaires generally show a low correlation to actual hearing deficit. For example, Widén, Holmes, Johnson, Bohlin, and Erlandsson (2009) found that only 27% of the subjects reporting subjective hearing loss also failed the hearing screening test.

Thus, although questionnaires are undoubtedly essential tools to evaluate the presence of NIHL or noise-induced symptoms such as tinnitus, there is a need to also implement more accurate measurements to quantify possible hearing or communication deficits.

### **3.3.2 Pure-tone audiometry**

Pure-tone audiometry is considered the gold standard for hearing evaluation. Although this test can be easily performed, there are several requirements to obtain accurate hearing thresholds such as requirements for the equipment and the availability of a soundproof room (International Organization for Standardization, 1989). Furthermore, the audiogram reflects the functioning of the entire auditory pathway, even though noise is considered to mainly affect the cochlea (Talaska & Schacht, 2007). The early stages of hearing loss may also be difficult to detect with pure-tone audiometry since a considerable amount of hair cells in the cochlea need to be damaged before a measurable level of hearing loss can be detected (Daniel, 2007). In addition, audiometry determines the sensitivity for pure tones, but not for more complex sounds such as speech signals. Hence, complementary tests which are sensitive to detect early noise-induced damage on the one hand, and tests that evaluate early complaints with speech intelligibility on the other hand, will be necessary when assessing the effects of noise on the auditory system.

### **3.3.3 Otoacoustic emissions**

Otoacoustic emissions (OAEs) are low-level sounds reflecting the non-linear active processes in the cochlea. Hence, OAE measurements can be used to determine the cochlear status, and more specific the OHC function (Hall & Lutman, 1999; Marshall, Lapsley Miller, & Heller, 2001). Clinical applications of OAEs are among others related to hearing screening, differential diagnosis of hearing loss and monitoring of hearing status (Hall, 2000d). There are two clinically relevant types of OAEs: transient evoked otoacoustic emissions (TEOAEs) and distortion product otoacoustic emissions (DPOAEs). TEOAEs and DPOAEs are, respectively, responses following a brief stimulus or following acoustic stimulation with two pure tones presented simultaneously. Furthermore, TEOAEs contain energy in the frequency range from 0.5 to 4.0 kHz (Probst, Lonsbury-Martin, & Martin, 1991), while DPOAEs can be reliably measured in the frequency region up to 8.0 kHz (Gorga et al., 1997). The OAE-technique has the advantage to be a non-invasive technique that is not influenced by the patient's state of consciousness. Besides, it is a fast and reliable technique to obtain objective information of the integrity of the OHCs, whereby the absence of OAEs or a

reduction in OAE amplitude may indicate a cochlear lesion on the condition that there is no conductive hearing impairment.

Regarding the effects of noise exposure on the auditory system, OAEs have been described as a valuable tool in the detection of subclinical OHC damage and preclinical hearing loss (e.g. Helleman, Jansen, & Dreschler, 2010; Job et al., 2009; Marshall et al., 2001; Rosanowski et al., 2006). Specifically, a reduction in OAE amplitude may reflect OHC damage due to noise exposure (Śliwinska-Kowalska & Kotylo, 2007). Moreover, several studies have indicated that OAEs have the ability to discriminate between normal-hearing subjects depending on their noise history, whereby OAE amplitudes tend to be lower in subjects exposed to noise compared to non-exposed subjects with similar audiometric hearing thresholds. (Attias, Horovitz, El-Hatib, & Nageris, 2001; Lucertini, Moleti, & Sisto, 2002). One study that focused on young adults exposed to leisure noise reported OHC damage in the absence of pure-tone hearing loss (Rosanowski et al., 2006). Therefore, identifying subclinical inner-ear damage will be an important factor in the assessment of young people exposed to noise.

A reduction in the amplitude of TEOAEs or DPOAEs has also been reported in tinnitus subjects (Ami, Abdullah, Awang, Liyab, & Saim, 2008; Kowalska & Sułkowski, 2001; Ozimek, Wicher, Szyfter, & Szymiec, 2006; Shiomi, Tsuji, Naito, Fujiki, & Yamamoto, 1997). Moreover, lower TEOAE amplitudes or DPOAE amplitudes were also found in tinnitus subjects without hearing loss, suggesting that subclinical OHC damage may be a factor in the generation of tinnitus (Granjeiro et al., 2008; Paglialonga, Del Bo, Ravazzani, & Tognola, 2010). Hence, the use of OAEs can be important in the investigation of subjects with tinnitus, especially in the absence of a clinical hearing loss (Granjeiro et al., 2008; McKee & Stephens, 1992; Paglialonga et al., 2010; Thabet, 2009). DPOAEs are mostly preferred in the evaluation of tinnitus patients as a sufficient number of frequencies per octave (e.g. eight) can be used to evaluate the OHC function (Dhar & Hall III, 2012). Besides, DPOAEs can identify hair cell dysfunction for frequency regions up to 8.0 or 10.0 kHz (Dhar & Hall III, 2012; Gorga et al., 1997; Hall, 2000c).

Limitations of OAEs include the impossibility to record responses in some cases due to the influences of external and middle ear conditions and the insensitivity to abnormalities of the

IHCs or higher levels of the auditory pathway (Hall, 2000b). Furthermore, as with pure-tone audiometry, measuring OAEs do not provide information about speech intelligibility in various listening situations.

### **3.3.4 Speech audiometry**

In speech audiometry standardized speech samples in the format of digits, mono- or bi-syllabic words or sentences are presented in order to measure the ability to understand speech.

As already described in the previous paragraphs, the first noticeable disability caused by noise exposure is often a reduced ability to understand speech in a noisy environment. Therefore, especially speech-in-noise tests have been considered to have an added value in the early detection of noise-induced hearing damage. In recent years, several speech-in-noise tests for screening NIHL have been developed and evaluated (Jansen, Luts, Dejonckere, Van Wieringen, & Wouters, 2013; Smits, Kapteyn, & Houtgast, 2004). The first screening tool in Dutch was developed by Smits et al. (2004) and consisted of a digit triplet test in noise that could be conducted by telephone. With a sensitivity and specificity of respectively 91% and 93%, this test was suitable for hearing screening in the general population (Smits et al., 2004). In the study of Jansen et al. (2013), the sensitivity and specificity of the Digit Triplet speech-in-noise test for detecting and monitoring early high-frequency hearing loss was evaluated in a group of noise-exposed workers. The Digit Triplet test proved to have a high sensitivity and specificity for detecting different degrees of high-frequency hearing loss. The use of such a screening test has several advantages in the screening for hearing loss (Jansen, 2013; Jansen et al., 2013). First, the speech and noise signals are presented at supra-threshold levels so that no soundproof room is required. Second, these tests were designed to be performed with standard audio equipment, which makes it possible to reach a broad public in an inexpensive way. Third, digit triplets have a lower redundancy compared to meaningful sentences, and might therefore be more sensitive to the first signs of hearing loss. Finally, a speech-in-noise test assesses the whole auditory pathway and is highly relevant for everyday communication .

In daily practice, subjects often indicate that listening in noisy situations is a challenging and often exhausting experience, even in the absence of a clinically significant hearing loss

measured by the standard tonal or speech audiometry tests (Committee on Hearing and Bioacoustics and biomechanics (CHABA), 1988). In a study of Broadbent (1958), speech recognition performance in various listening conditions was examined in young normal-hearing participants. Results revealed that although speech intelligibility remained unchanged across the listening conditions, more mental effort was required to remain speech intelligibility in the difficult listening condition. Hence, a person's perceived difficulty of the listening situation will also be very important to consider, though this cannot be detected by the standard audiological measurements (Bourland-Hicks & Tharpe, 2002; Gosselin & Gagne, 2010).

Based on studies concerning speech understanding in especially older adults, it was suggested that beyond the peripheral factors (i.e. the ability to hear), there are some central cognitive correlates of speech understanding that are essential for sufficient communication abilities (Akeroyd, 2008; Pichora-Fuller et al., 1995; Schneider, Daneman, & Pichora-Fuller, 2002). The additional impact of these cognitive correlates for speech understanding seemed to be small in the above described speech-in-noise screening test of Jansen (2013), which may therefore not be suitable to detect and differentiate the degree of difficulty and effort related to speech understanding in persons with similar peripheral hearing thresholds. In this respect, an evaluation of the cognitive correlates for speech processing may provide additional and useful information over and beyond traditional speech recognition scores.

### **3.3.5 Listening effort**

Listening effort is an important dimension of speech understanding since the central cognitive system is largely involved in the process of listening, comprehending and responding (Figure 3.1) (Baltes & Lindenberger, 1997; Pichora-Fuller & Singh, 2006; Sweetow & Henderson-Sabes, 2004). Listening is the process of hearing with intention and attention (Sweetow & Henderson-Sabes, 2004). Comprehension involves the ability to use contextual, linguistic and grammatical information to understand the meaning and intent of spoken language, while responding refers to the information stored in memory and the ability to formulate a response (Kiessling et al., 2003; Pichora-Fuller & Singh, 2006; Sweetow & Henderson-Sabes, 2004).



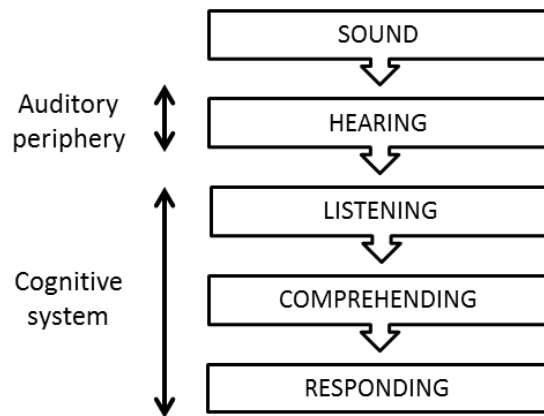


Figure 3.1 Components of communication. Partially based on Sweetow and Henderson-Sabes. The case for LACE (Listening and Communication Enhancement). *Hear J.* 2004;57:32-38

Some specific cognitive functions have been shown to be related to the process of speech understanding, namely working memory, speed of processing and attention (Akeroyd, 2008; Pichora-Fuller et al., 1995). Listening to speech in noisy situations may require more cognitive resources because the information in the speech signal degrades by the presence of background noise. Consequently, when a listener must expend more cognitive resources in order to understand speech, the listening task becomes more difficult and effortful. In the literature, the cognitive requirements necessary to understand speech have been defined as listening effort (Bourland-Hicks & Tharpe, 2002).

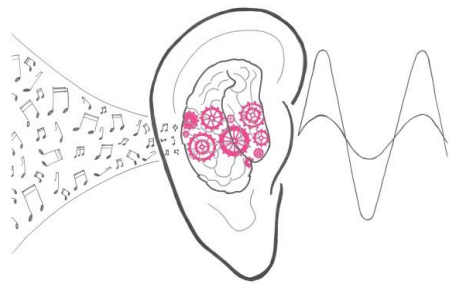
Several methods exist for measuring listening effort. First, listening effort can be evaluated through psychophysiological measures such as pupillometry (e.g. Engelhardt, Ferreira, & Patsenko, 2010; Kuchinsky et al., 2013), eye movement tracking (Ben-David et al., 2011), galvanic skin response, electromyographic activity, heart rate variability (Mackersie & Cones, 2011; Mackersie, MacPhee, & Heldt, 2015), and electroencephalography (EEG) frequency bands (Obleser, Wöstmann, Hellbernd, Wilsch, & Maess, 2012). Another method that quantifies listening effort is based on a dual-task paradigm (Bourland-Hicks & Tharpe, 2002; Fraser, Gagné, Alepins, & Dubois, 2010; Gosselin & Gagne, 2011; Howard, Munro, & Plack, 2010; Rabbitt, 1966; Sarampalis, Kalluri, Edwards, & Hafter, 2009), which consists of performing a primary task while simultaneously conducting a concurrent secondary task. The primary task typically consists of a listening task such as word recognition in quiet or in background noise (Gosselin & Gagne, 2010). The secondary task may consist of a memory task, a probe reaction time task, or a tactile pattern recognition task (Bourland-Hicks &

Tharpe, 2002; Desjardins & Doherty, 2013; Downs, 1982; Feuerstein, 1992; Fraser et al., 2010; Gosselin & Gagne, 2011).

The dual-task paradigm is based on the theory that the brain has a limited capacity to respond to all sensory systems (Broadbent, 1958; Kahneman, 1973). Moreover, it is hypothesized that this brain capacity is allocated across the sensory systems involved in a specific task (Kahneman, 1973). Hence, when the cognitive requirements for one task increase, less resources will be available to perform a secondary task (Downs & Crum, 1978; Kahneman, 1973), which in turn increases listening effort (Broadbent, 1958; Downs, 1982). It is assumed that in situations of increased listening effort (e.g. when adding noise to the listening task), fewer cognitive resources will be available to perform other tasks (Broadbent, 1958). In case of, for example, a memory task, fewer items can be stored in the working memory, so that performance on the memory task will decrease. An important advantage of measuring listening effort is, therefore, that it can provide additional information over and beyond traditional speech audiometry (Gosselin & Gagne, 2010). Psychophysiological measures can provide an objective measure of listening effort as they measure involuntary reactions (e.g. pupil dilatation). However, more specialized equipment is needed to implement these psychophysiological measures. Dual-task paradigms are more easily to implement and are more related to person's daily activities. A disadvantage of dual-task paradigms that use memory tasks or reaction time measurements concerns their sensitivity to floor or ceiling effects (Picou, 2013).

Regarding the effects of noise exposure on the auditory system, the previous paragraphs described that subjects with NIHL often report difficulties with speech understanding, especially in adverse listening situations (Daniel, 2007). In general, distortion of the incoming speech signals because of hearing deficits or background noise require more higher-level cognitive resources to compensate for lower-level loss of information (Schneider et al., 2002). Hence, listening in noise can become more difficult and effortful for subjects with hearing loss. Apart from hearing loss, subjects with tinnitus also often report concentration difficulties (Andersson et al., 1999; Hallam et al., 2004; Tyler & Baker, 1983). As suggested by previous research, tinnitus may impair cognitive processing and more specific working memory capacity, as well as selective and divided attention (Andersson & McKenna, 2006; Gatehouse, 1991; Jacobson et al., 1996).

Thus, a test for measuring listening effort, complementary to the methods described above, may be useful in the assessment of noise-exposed subjects and subjects with tinnitus as they often report concentration difficulties or increased effort associated with speech understanding. However, to the best of our knowledge, no research exists pertaining to the effects of NIHL or NIT on the amount of listening effort.



# CHAPTER 4

## Research goals



## 4.1 Research aims

Exposure to noise constitutes a health risk, as there is sufficient scientific evidence that excessive noise levels can induce hearing damage (e.g. Basner et al., 2014; Miller, 1974). However, in the case of leisure noise exposure, there is still no consensus about the extent of the risk, particularly in young people. Furthermore, tinnitus, either temporary or chronic, seems to be a common reported symptom after exposure to noise and can have a significant impact on communication and the quality of life. The main objective of this thesis was, therefore, to determine and describe the effects of leisure noise exposure on the auditory system in Flemish young adults, with special attention to the presence and impact of tinnitus. To achieve this objective, six studies were conducted and will be presented in three chapters as described in Table 4.1.

Table 4.1 Overview of the research aims of the present thesis.

Chapter	PART	Aims
<b>Ch. 5 Epidemiology</b>	I	Determine the prevalence and risk factors for hearing damage after leisure noise exposure in Flemish young adults.
	II	Determine the prevalence and risk factors for tinnitus after leisure noise exposure in Flemish young adults.
<b>Ch. 6 Audiological assessment</b>	I	Evaluate the audiological characteristics of tinnitus after leisure noise exposure in Flemish young adults.
	II	Evaluate if tinnitus characteristics and associated factors have an impact on tinnitus-related handicap in adults with chronic tinnitus.
<b>Ch. 7 Listening effort</b>	I	The use of a dual-task test to measure listening effort in adults: the effects of age.
	II	Examine the effect of chronic noise-induced tinnitus on listening effort in normal-hearing young adults.

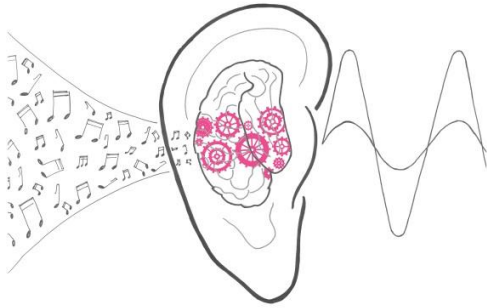
## 4.2 Research outlines

Identifying subjects at risk for acquiring hearing damage or noise-induced symptoms such as tinnitus is crucial in order to prevent future damage. Determining the prevalence of hearing damage and/or tinnitus as well as evaluating various factors that may be involved in the risk for acquiring such symptoms is therefore important. Hence, **Chapter 5** reports on the prevalence and risk factors for hearing damage and tinnitus after leisure noise exposure in Flemish young adults. **Part I and part II of chapter 5** comprise the studies on the prevalence of hearing damage and of both temporary and chronic tinnitus in Flemish young adults

between 18 and 30 years. In addition, the relation between leisure noise exposure and both the hearing status and the presence of tinnitus was examined as well as their association with baseline sociodemographic factors, health-related variables, attitudes and beliefs towards noise, hearing loss and HPDs.

Worldwide, tinnitus appears to be one of the most common reported symptoms after exposure to noise and its presence can be a sign of overexposure. Hence, there is a great need for tinnitus clinics to include appropriate audiological procedures in the assessment of tinnitus. Furthermore, it is important to identify tinnitus patients in need for intervention since tinnitus can have a significant impact on the quality of life. There are several methods and questionnaires available for evaluating the severity of tinnitus. However, there is still no consensus about their usefulness. Moreover, it remains unclear which factors influence tinnitus severity. Therefore, **chapter 6** describes the audiological assessment in tinnitus subjects. In **part I of chapter 6**, the characteristics of temporary and chronic tinnitus after exposure to leisure noise, measured in a group of students between 18 and 30 years, are presented. In addition, the influence of tinnitus on hair cell activity was examined by measuring TEOAEs and DPOAEs in the subjects reporting chronic tinnitus. **Part II of chapter 6** presents the (psychoacoustic) characteristics of tinnitus and tinnitus-related variables measured by current audiological assessment methods and questionnaires in adults (18-73 years) with chronic tinnitus. It was investigated whether these characteristics and variables independently affect tinnitus-related handicap.

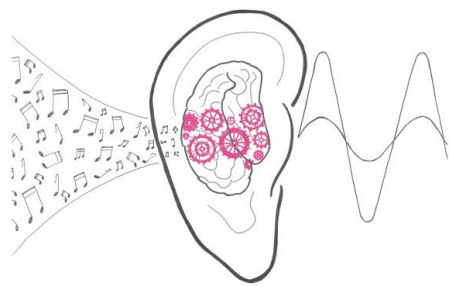
In addition to the known risks of noise exposure on hearing, there is growing evidence that tinnitus can affect central cognitive processes that are involved in the process of listening and comprehending. A test for measuring listening effort would therefore be useful, though factors such as age should be taken into account when interpreting the results. Hence, **chapter 7** is dedicated to listening effort. **Part I of chapter 7** presents a test for measuring listening effort. This test was evaluated in a general population of adults between 18 and 77 years and more specific, it was investigated whether age significantly affects the amount of listening effort. In **part II of chapter 7**, the amount of listening effort was measured in a group of young adults (18-30 years) with chronic tinnitus and a matched-control group in order to evaluate if the experience of tinnitus affects listening effort in several listening conditions.



## **PUBLICATIONS**







## CHAPTER 5

### Prevalence of noise-induced damage in Flemish young adults

## PART I

### Epidemiology and risk factors for leisure noise-induced hearing damage in Flemish young adults

Based on:

Degeest, S., Clays, E., Corthals, P., & Keppler, H. (2017). Epidemiology and risk factors for leisure noise-induced hearing damage in Flemish young adults. *Noise and Health*, 19(86), 10-19

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**Abstract**

**Purpose.** Young people regularly expose themselves to leisure noise and are at risk for acquiring hearing damage. This study compared young adults' hearing status in relation to sociodemographic variables, leisure noise exposure and attitudes and beliefs towards noise.

**Method.** 517 subjects between 18-30 years were included. A self-administered questionnaire regarding hearing, the amount of leisure noise exposure and attitudes towards noise and hearing protection as well as an audiological test battery were completed. Based on their hearing status, participants were categorized into normal hearing, subclinical hearing loss or clinical hearing loss.

**Results.** Age was significantly related to hearing status. Although the subjects in this study frequently participated in leisure activities, no significant associations between leisure noise exposure and hearing status could be detected. No relation with subjects' attitudes or the use of HPDs was found.

**Conclusions.** This study did not demonstrate clinically significant leisure noise-induced hearing damage, which may lead to more non-protective behaviour. However, the effects of leisure noise may become noticeable over the long term since age was found to be related with subclinical hearing loss. Longitudinal studies are needed to evaluate the long-term effects of noise exposure. Furthermore, preventive campaigns should further focus on self-experienced symptoms in order to make young adults aware of the harmful effects of excessive noise exposure.

### 5.1.1 Introduction

It is well known that exposure to excessive noise levels can induce metabolic and mechanical changes in the organ of Corti, leading to noise-induced hearing loss (NIHL) (Talaska & Schacht, 2007). Besides occupational noise exposure, there is growing concern about the risk of noise exposure during leisure activities, especially in teenagers and young adults. Regular exposure to high noise levels at nightclubs, discotheques and live concerts (Beach, Williams, et al., 2013; Jokitulppo, 2003; Keppler, Dhooge, & Vinck, 2015b; Serra et al., 2005; Smith et al., 2000) as well as exposure to high sound levels from personal music players (PMPs) (Keppler, Dhooge, Maes, et al., 2010; Meyer-Bisch, 1996) are reported among these young individuals and therefore might pose risks to hearing.

Several studies were conducted to determine the prevalence of leisure NIHL among teenagers and young adults. Some studies reported that NIHL is a common problem in young people as they found an increase in high frequency hearing loss (Montgomery & Fujikawa, 1992; Shargorodsky, Curhan, Curhan, & Eavey, 2010). Other studies, however, could not find such results (Henderson et al., 2011; Persson et al., 1993; Rabinowitz et al., 2006). The diagnosis of hearing loss should be based on pure-tone averages (PTAs) or audiogram notches in combination with a clear case history (Schlauch & Carney, 2012; Tharpe & Bess, 1999). Hence, a possible explanation for the inconsistencies that were found may be attributed to variation in the estimation of hearing levels using pure-tone audiometry as well as to differences in the definition of normal hearing (Schlauch & Carney, 2012). Moreover, the early stages of hearing loss may also be difficult to detect since only after a considerable amount of hair cells in the cochlea have been damaged effects are measurable with pure-tone audiometry (Daniel, 2007; Hall & Lutman, 1999). Otoacoustic emissions (OAEs), which reflect the cochlear outer hair cell (OHC) function, have therefore been proposed as valuable tools for identifying preclinical NIHL (Lapsley Miller & Marshall, 2007; Marshall et al., 2001). OAEs may be particularly useful to evaluate the effect of noise on hearing as the OHCs are known to be the most vulnerable structures of the auditory organ with respect to excessive noise exposure (Rask-Andersen, Ekvall, Scholtz, & Schrott-Fischer, 2000).

In addition to the differences in prevalence estimates, there is no consensus about the extent of the risk of hearing loss resulting from leisure noise exposure. Some studies point to

a relation between hearing deterioration and exposure to leisure noise (Martinez-Wbaldo et al., 2009; Spaeth, Klimek, Döring, Rosendahl, & Mösges, 1993), while others conclude that leisure noise has no or minimal effects on hearing as no or only slight correlations were found between hearing thresholds and leisure noise exposure (Axelsson, Jerson, Lindberg, & Lindgren, 1981; Carter, Waugh, Keen, Murray, & Bulteau, 1982; Fleischer & Müller, 2005; Lindeman, Van der Klaauw, & Platenburg-Gits, 1987; Mercier & Hohmann, 2002; Mostafapour, Lahargoue, & Gates, 1998). In order to estimate a realistic risk of NIHL, those leisure activities that result in excessive noise exposure should be identified (Beach, Williams, et al., 2013). Although it is known that young adults participate in several leisure activities and that leisure habits may change during different phases of life (Beach, Gilliver, et al., 2013; Biassoni et al., 2014; Jokitulppo, 2003; Jokitulppo et al., 1997; Meyer-Bisch, 1996), previous research mostly focused on specific noise sources only. For example, leisure noise exposure from sources others than from PMPs or attending night clubs have mostly been neglected in other studies. Moreover, the risk of hearing damage also increases with noise intensity and exposure time (Hellström, Axelsson, & Costa, 1998). Therefore, the participation of young people in several noisy activities as well as the corresponding accumulated lifetime noise exposure are important factors to consider (Beach, Williams, et al., 2013; Jokitulppo et al., 2006). However, information on the number of years of exposure is often missing.

The risk of hearing damage also appears to be related to a person's attitude towards noise, hearing loss and hearing protection devices (HPDs). One study by Keppler, Dhooge, and Vinck (2015a) found significantly worse hearing thresholds in young adults who considered noise not that risky or who experienced more barriers against wearing HPDs. In the current study, the theoretical framework developed by Widén (2013) was used to explain young people's attitudes and behaviours towards leisure noise exposure. The model combines all the factors from the Theory of Planned Behaviour (TPB) (Ajzen, 1991); these are attitudes, subjective norms and perceived behavioural control, with the perceived benefits and barriers to modifying the behaviour and triggers to action from the Health Belief Model (HBM) (Rosenstock, 1974). Attitudes are described as the tendency to respond positively or negatively towards a certain phenomenon. In addition, the intention to engage or not to engage in a particular behaviour (e.g. wearing HPDs) will be determined by subjective norms,

whereas behavioural control refers to an individual's perception about the ease or difficulty of undertaking a specific behaviour. Perceived benefits and barriers with the actual behaviour can influence changing risk-taking behaviour into health-oriented behaviour. Besides, the experience of certain symptoms (e.g. hearing-related problems) can also be a trigger to behavioural change (Rosenstock, 1974). In addition to the factors of the TPB and HBM, a factor risk perception was added in the model of Widén (2013), which deals with an individual's awareness of the risks of noise exposure.

The main objective of this study was to determine the prevalence of noise-induced hearing damage in a group of Flemish young adults between 18 and 30 years as well as to explore the association with baseline sociodemographic factors, the amount of noise exposure and attitudes and beliefs towards noise, hearing loss and HPDs as outlined by the model of Widén (2013). The hypothesis was that hearing may be affected in young adults with increased accumulated leisure noise exposure as measured by pure-tone audiometry and OAEs. In case of normal pure-tone audiometry, preclinical hearing damage may be measured through reduced OAE amplitudes or the absence of OAEs. Furthermore, based on the model of Widén (2013), it can be hypothesized that young adults yielding pro-noise attitudes may use HPDs infrequently and therefore may be more at risk for acquiring hearing loss. Hence, such information may increase knowledge about the effects of leisure noise on the hearing of young adults.

## **5.1.2 Method**

### **5.1.2.1 Study sample**

This study was a cross-sectional study involving a self-administered questionnaire and a hearing assessment, consisting of an otoscopic evaluation, admittance measures, pure-tone audiometry, and measurements of transient evoked otoacoustic emissions (TEOAEs) and distortion product otoacoustic emissions (DPOAEs). A noise-free period of at least 12 hours before testing was required in order to rule out the presence of transient threshold shifts.

A cohort of young adults between 18 and 30 years was recruited in Flanders, the northern region of Belgium. It was ensured that approximately equal samples of men and woman were recruited from the different regions in Flanders with a wide variation in age and professional status. Within a variety of settings - Flemish companies, universities and public

places (e.g. sports clubs and youth associations) - individuals were invited to participate in the study by distributing an invitation letter through email, online (school) platforms or posters. Individuals who were interested to participate in the study contacted the researchers by email.

A total of 540 young adults voluntarily participated in the study. Participants were excluded in case of abnormalities of the external ear, abnormal middle-ear function as measured by tympanometry or acoustic stapedius reflex thresholds, or when they did not complete the questionnaire correctly. Therefore, the responses of 517 young adults were further analyzed, i.e. a drop out of 4.3%. The final sample consisted of 307 females (mean=22.2 years; SD=3.67; range 18 – 30 years) and 210 males (mean=23.8 years; SD=3.12; range 18 – 30 years). The majority of the sample (59.6%) were students, 39.5% had a permanent job and 1.4% was unemployed.

All testing was carried out in a quiet room. To enable accurate testing, the ambient sound pressure levels at each frequency band between 0.25 and 8.0 kHz were measured using a 2250-B Brüel en Kjaer real time sound analyzer (Brüel & Kjær, Denmark). It was ensured that the ambient sound pressure levels did not exceed any of the levels specified by the ISO 8253-1 guidelines for accurate testing of normal air conduction hearing threshold levels (International Organization for Standardization, 1989).

The study was approved by the Ethical Committee of Ghent University Hospital and was conducted in accordance with the ethical standards stipulated in the Helsinki declaration for research involving human subjects. All participants agreed with the informed consent, in which the aims of the study were described.

### **5.1.2.2 Questionnaire**

A questionnaire was designed based on available literature regarding leisure noise exposure and the assessment of noise-induced tinnitus and NIHL (Jokitulppo et al, 2006; Keppler, 2010; Svensson et al, 2004; Widén et al, 2006). After a try out on 30 subjects ranging in age from 18 to 30 years who were not included in the study, the translucency of some items and the adequacy of some response alternatives were adjusted. The final questionnaire comprised 44 items distributed over five sections.



The first section included several sociodemographic variables. Participants were asked about their age, gender and professional status (employee, unemployed or student).

The second section consisted of questions regarding subjective hearing status and medical history concerning ear-related disorders.

In the third section of the questionnaire, the amount of leisure noise exposure and the amount of time the respondent wore HPDs was recorded for several leisure activities that are common among young adults such as visiting nightclubs and playing musical instruments. In addition, the amount of occupational noise exposure was also recorded in order to control for as a possible confounding factor. For each activity, the weekly equivalent noise exposure ( $L_{Aeq,w}$ ) as well as the lifetime equivalent noise exposure ( $L_{Aeq,l}$ ) were calculated. More information regarding the calculation of the weekly and lifetime noise exposure, based on Jokitulppo et al. (2006), is available elsewhere (Degeest, Keppler, Corthals, & Clays, 2016; Keppler, Dhooge, et al., 2015b). In addition, the maximum lifetime equivalent noise exposure (maximum  $L_{Aeq,l}$ ) was also determined for each participant.

The fourth questionnaire section consisted of a Dutch modified version of the 'Youth Attitude to Noise Scale' (YANS) (Keppler, 2010; Widén, Holmes, & Erlandsson, 2006) and a Dutch modified version of the 'Beliefs about Hearing Protection and Hearing Loss' (BAHPHL) (Keppler, 2010; Svensson, Morata, Nylen, Krieg, & Johnson, 2004). The YANS evaluates a subject's attitude towards noise and consists of 19 items that are measured using a five-point Likert scale ranging from 'totally disagree' to 'totally agree'. A higher score on the YANS indicates a positive attitude, where noise is seen as unproblematic. The 19 items were divided over four factors representing attitudes towards noise associated with elements of youth culture (factor 1: 8 items), the ability to concentrate in noisy environments (factor 2: 3 items), daily noises (factor 3: 4 items), and intent to influence the sound environment (factor 4: 4 items) (Widén et al., 2006). The BAHPHL instrument evaluates the attitudes towards hearing loss and HPDs and contained 24 items which can be divided over seven factors: susceptibility to hearing loss (factor 1: 6 items), severity of consequences of hearing loss (factor 2: 3 items), benefits of preventive action (factor 3: 3 items), barriers to preventive action (factor 4: 4 items), behavioural intentions (factor 5: 3 items), social norms (factor 6: 2 items), and self-efficacy (factor 7: 3 items) (Svensson et al., 2004). Consistent with the YANS,

the items were evaluated by a five-point Likert scale with higher scores corresponding to a more positive attitude, meaning that one does not care about the possible consequences of hearing loss and is unaware of the benefits of wearing HPDs.

The fifth and last part of the questionnaire included questions regarding the presence and characteristics of tinnitus (e.g. localization of the tinnitus, duration of the tinnitus, subjective experience of tinnitus pitch and loudness) after leisure noise exposure and whether the tinnitus was temporary or chronic. Temporary tinnitus was defined as disappearing within 72 hours after the exposure to leisure noise. Information about the prevalence and risk factors for tinnitus is described elsewhere (Degeest, Keppler, et al., 2016).

### **5.1.2.3 Audiometric evaluation**

Pure-tone audiometry was performed using the modified Hughson-Westlake method for air conduction thresholds at conventional octave frequencies from 0.25 to 8.0 kHz and half octave frequencies 3.0 and 6.0 kHz (AA222 Audio Traveller and TDH39 headphones Interacoustics, Assens, Denmark). For each participant, the PTA for low- and mid-frequencies was calculated as the average of air conduction thresholds at 0.5, 1.0 and 2.0 kHz (further on denoted as  $PTA_{low}$ ). The PTA for high frequencies (further on denoted as  $PTA_{high}$ ) was calculated as the average of air conduction thresholds at 3.0, 4.0, 6.0 and 8.0 kHz (Tharpe & Bess, 1999).

### **5.1.2.4 Otoacoustic emissions**

Both TEOAEs and DPOAEs were measured as TEOAEs test a large proportion of the cochlea simultaneously, while DPOAEs can be used to evaluate the cochlear function for higher frequency regions up to 8.0 or 10.0 kHz (Hall, 2000c). In this respect, both methods are an effective way to measure the OHC function and enhances the sensitivity to detect OHC damage.

TEOAEs and DPOAEs were measured using the DPOAE probe (ILO 292 USB II module with Otodynamics Ltd. ILOv6 software ). The probe was calibrated before each measurement using the 1 cc calibration cavity provided by the manufacturer.

The non-linear differential stimulus paradigm was used for TEOAE measurements. Rectangular pulses of 80  $\mu$ s at a rate of 50 clicks per second were delivered at an intensity of

80 ± 2 dBpeSPL. Registration of TEOAEs was terminated after 260 accepted sweeps with a noise rejection setting of 4 mPa. Emissions and noise amplitudes were calculated in half octave-frequency bands centred at 1.0, 1.5, 2.0, 3.0 and 4.0 kHz using ad hoc software. Only measurements with probe stability of 90% or better were considered as valid measurements. TEOAEs were further analyzed in terms of their presence/absence, whereby TEOAEs were considered present if the signal-to-noise ratio (SNR) was at least 3 dB in three or more half-octave frequency bands.

DPOAEs were measured with primary tone level combinations of L1/L2=65/55 dB SPL. The f1/f2 ratio was 1.22, with f2 ranging from 0.841 to 8.0 kHz at eight points per octave. A noise artefact rejection level of 6 mPa was used and the whole frequency range was looped until the noise amplitude fell below -5 dB SPL at individual frequencies. Emission and noise amplitude were averaged for half-octave frequency bands with center frequencies 1.0, 1.5, 2.0, 3.0, 4.0, 6.0 and 8.0 kHz. Like TEOAEs, DPOAEs were further analyzed in terms of their presence/absence, whereby DPOAEs were considered present if the SNR was at least 3 dB in five or more half-octave frequency bands.

#### **5.1.2.5 Statistical analysis**

Statistical analysis was performed using SPSS version 21 (SPSS Inc. Chicago IL, USA). Descriptive parameters were established for the hearing assessment and questionnaire outcomes. Results of the hearing assessment were provided for both ears, but only one ear was selected for further statistical analysis.

Based on the hearing assessment data, three groups were created: (1) subjects with normal hearing; (2) subjects with subclinical hearing loss; and (3) subjects with clinical hearing loss. A person was considered having normal hearing if the  $PTA_{low}$  and  $PTA_{high}$  were respectively equal or better than 20 dB HL and 25 dB HL (Tharpe & Bess, 1999) and if TEOAEs and DPOAEs were present. If no shifts in  $PTA_{low}$  and  $PTA_{high}$  were found but TEOAEs or DPOAEs were absent, a person was considered having subclinical hearing loss. Clinical hearing loss was considered if a shift in  $PTA_{low}$  or  $PTA_{high}$  was found and TEOAEs or DPOAEs were absent. For further analysis, the worst ear was selected in case of a (sub)clinical hearing loss. In case of normal hearing, one ear was chosen at random.

Subsequently, the distribution of all participants was illustrated with respect to baseline sociodemographic variables as well as the amount of noise exposure and attitudes and beliefs towards noise, hearing loss and HPDs. Besides, for each of these variables, chi-square tests or independent samples t-test were performed to evaluate their univariate relation with the groups based on hearing status. For all statistical analyses, a significance level of 0.05 was used.

Finally, binary logistic regression analysis (enter method) was used to examine the association between the groups based on hearing status and the maximum  $L_{Aeq,l}$  and age (Model 1). Moreover, this association was further estimated in several models including following covariates: Model 2: gender and employment status; Model 3: use of HPDs; and Model 4: entire score on the YANS and BAHPHL instrument.

### 5.1.3 Results

#### 5.1.3.1 Hearing status

Figure 5.1 shows the mean hearing thresholds for the right and left ears of all participants. According to an independent samples t-test, no significant differences were found between right and left ears for all frequencies tested ( $p > 0.05$ ). The mean  $PTA_{low}$  was 3.3 dB (SD 3.91; range -6.67 – 20.00 dB) for the right ears and 2.2 dB (SD 3.95; range -8.33 – 18.33 dB) for the left ears. In case of the  $PTA_{high}$ , a mean of 3.0 dB (SD 4.94; range -7.50 – 22.50 dB) was found for the right ears and 2.8 dB (SD 5.24; range -10.00 – 22.50 dB) for the left ears.

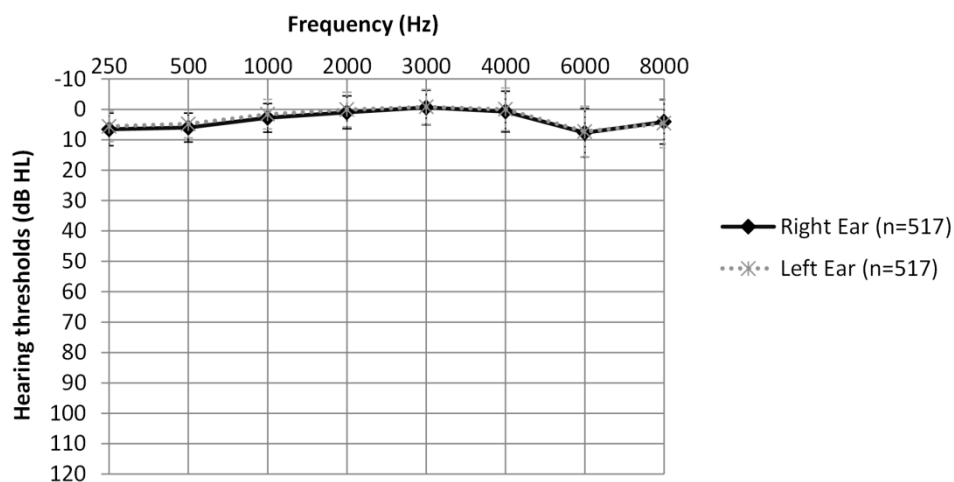


Figure 5.1 Mean  $\pm$  one standard deviation of pure-tone air conduction hearing thresholds for right ears (solid line) and left ears (dashed line).

The mean TEOAE and DPOAE amplitudes for right ears and left ears are shown in Figure 5.2. When TEOAEs and DPOAEs were analyzed in terms of their presence/absence, no significant differences were found between right and left ears according to chi-square tests ( $p>0.05$ ). TEOAEs were absent in 6.7% of the right ears and 9.0% of the left ears. DPOAEs were absent in 7.1% of the right ears and 7.0% of the left ears. Furthermore, the values for  $PTA_{low}$  and  $PTA_{high}$  were compared between absent and present TEOAEs and DPOAEs using independent samples t-tests. Values for both the  $PTA_{low}$  and  $PTA_{high}$  were significantly higher when TEOAEs or DPOAEs were absent ( $p<0.05$ ) (Table 5.1).

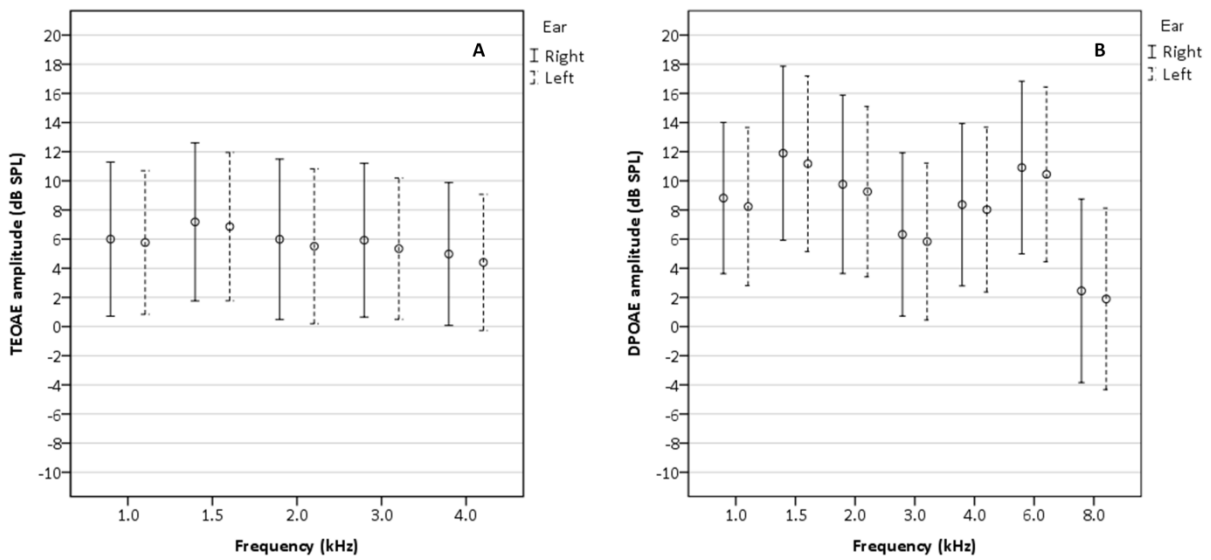


Figure 5.2 Mean  $\pm$  one standard deviation of TEOAE amplitudes (a) and DPOAE amplitudes (b) for right ears and left ears.

Table 5.1  $PTA_{low}$  and  $PTA_{high}$  values for absent and present TEOAEs and DPOAEs in right ears and left ears of all participants (n=517).

		Absent/Present	n	Mean	SD	Test statistic	P
<b>TEOAEs</b>							
Right ear	$PTA_{low}$	Absent	33	6.2	5.07	<b>t=4.970</b>	<b>&lt;0.001</b>
		Present	461	2.9	3.61		
	$PTA_{high}$	Absent	33	5.9	5.00		
		Present	461	2.6	4.83		
Left ear	$PTA_{low}$	Absent	45	6.0	4.39	<b>t=7.287</b>	<b>&lt;0.001</b>
		Present	457	1.8	3.67		
	$PTA_{high}$	Absent	45	7.4	5.58		
		Present	457	2.3	4.93		

Table 5.1 (continued).

		Absent/Present	n	Mean	SD	Test statistic	P
<b>DPOAEs</b>							
Right ear	PTA <sub>low</sub>	Absent	35	7.8	5.45	<b>t=7.964</b>	<b>&lt;0.001</b>
		Present	459	2.7	3.42		
	PTA <sub>high</sub>	Absent	35	6.7	5.22	<b>t=4.960</b>	<b>&lt;0.001</b>
		Present	459	2.5	4.76		
Left ear	PTA <sub>low</sub>	Absent	35	5.8	4.69	<b>t=5.801</b>	<b>&lt;0.001</b>
		Present	467	1.9	3.73		
	PTA <sub>high</sub>	Absent	35	9.0	5.33	<b>t=7.825</b>	<b>&lt;0.001</b>
		Present	467	2.3	4.88		

Based on their hearing status determined by pure-tone audiometry and both TEOAEs and DPOAEs, 436 (84.3%) participants were classified with normal hearing, and 81 (15.7%) participants were classified with subclinical hearing loss. None of the participants in this study could be classified with clinical hearing loss, so that further analysis will be based on the groups with normal hearing and subclinical hearing loss. Table 5.2 shows the mean PTA-values as well as the number of present and absent TEOAEs and DPOAEs for the subjects with normal hearing and subjects with subclinical hearing loss.

Table 5.2 PTA<sub>low</sub> and PTA<sub>high</sub> values and number of present and absent TEOAEs and DPOAEs in subjects with normal hearing (n=436) and subjects with subclinical hearing loss (n=81).

	Hearing thresholds		TEOAEs		DPOAEs	
	PTA <sub>low</sub> mean±SD	PTA <sub>high</sub> mean±SD	Present % (n)	Absent % (n)	Present % (n)	Absent % (n)
Normal hearing	2.6±3.45	3.4±4.53	100 (436)	0 (0)	100 (436)	0 (0)
Subclinical hearing loss	5.8±4.60	7.7±5.50	29.6 (24)	70.4 (57)	34.6 (28)	65.4 (53)

### 5.1.3.2 Univariate associations with hearing status

**Baseline sociodemographic variables.** An overview of the baseline sociodemographic variables is presented in Table 5.3. Univariate analysis with the groups based on hearing status showed that subjects with subclinical hearing loss were significantly older (mean=24.1 years; SD=3.68) than subjects with normal hearing (mean=22.6 years; SD=3.47),  $t(515)=-3.451$ ;  $p=0.001$ . No significant association was found with gender ( $\chi^2=1.578$ ;  $p>0.05$ ). Finally, employment status was significantly associated with hearing status ( $\chi^2=7.467$ ;  $p=0.006$ ),

whereby unemployed subjects or students had normal hearing (63.1%) more often compared to employed subjects, who had subclinical hearing loss more frequently (53.1%).

Table 5.3 Overview of the baseline sociodemographics variables for the total sample (n=517) as well as distributed for the groups based on hearing status.

Variable		Total sample (n=517)	Hearing status	
			Normal	Subclinical hearing loss
Age	mean ( $\pm$ SD)	22.8 (3.54)	22.6 (3.47)	24.1 (3.68)
Gender	% (n)			
-Male		40.6 (210)	39.4% (172)	46.9% (38)
-Female		59.4 (307)	60.6% (264)	53.1% (43)
Employment status	% (n)			
-Employee		39.5 (204)	36.9% (161)	53.1% (43)
-Not unemployed or Student		60.5 (313)	63.1% (275)	46.9% (38)

**Leisure noise exposure and the use of HPDs.** In Table 5.4, an overview of the subjects' attendance, the average time spent per week, number of years, self-estimated median loudness and the average weekly and lifetime noise exposure for the different leisure activities is given. The highest attendance was found for watching movies or plays (95.6%), visiting nightclubs or music venues (92.5%) and attending musical concerts or festivals (85.5%). Furthermore, visiting nightclubs and music venues as well as attending musical concerts and festivals were described as the loudest, where one must shout over a near distance. Out of these activities, visiting nightclubs and music venues amounted to the highest noise exposure, with respectively an average weekly and lifetime equivalent noise exposure of 73.7 dBA (SD 10.54; 32.84 – 99.42 dBA) and 81.1 dBA (SD 10.41; 39.83 – 106.53 dBA). For all of the activities, the majority of the participants did not wear HPDs. The highest grades of wearing HPDs were found for attending musical concerts (26.2%), using noisy tools (24.7%) or occupational noise exposure (25.3%).

Table 5.4 Percentage of subject's attendance, mean hours per week and mean number of years participating in each activity as well as the median loudness, mean A-weighted equivalent SPLs in dBA and the percentage of subjects wearing HPDs for each of the activities (n=517).

Activity	Attendance (%)	Time spent		Loudness	L <sub>Aeq, w</sub> (dBA)	L <sub>Aeq, l</sub> (dBA)	Wearing HPDs (%)
		Per week mean (SD)	Years mean (SD)				
Watching movies or plays	95.6	0.4 (1.01)	10.3 (4.50)	Loud conversation	50.0 (8.49)	59.6 (8.64)	1.6
Visiting nightclubs or music venues	92.5	5.7 (7.41)	6.3 (3.24)	Shout over near distance	73.7 (10.54)	81.1 (10.41)	17.2
Attending musical concerts or festivals	85.5	0.5 (1.09)	5.6 (3.11)	Shout over near distance	64.4 (8.88)	71.2 (9.33)	26.2
Listening to PMPs through headphones	84.5	5.8 (8.35)	7.1 (3.60)	Loud conversation	58.2 (12.19)	66.0 (12.79)	n.a
Listening to a home stereo or radio	69.4	10.6 (11.26)	10.0 (6.55)	Loud conversation	58.2 (8.82)	67.1 (9.39)	0
Attending sport events	49.7	1.5 (2.35)	7.5 (5.02)	Shout over 1 m	51.7 (9.73)	59.3 (11.07)	1.2
Using noisy tools	28.2	3.5 (11.12)	5.7 (4.74)	Loud conversation	61.7(13.67)	67.8 (13.72)	24.7
Practicing a musical instrument	26.7	3.1 (3.34)	9.6 (4.85)	Shout over 1 m	56.4 (11.66)	65.2 (11.85)	1.4
Occupational noise	15.3	18.5 (20.02)	3.5 (2.86)	Shout over 1 m	68.5 (12.41)	72.3 (13.37)	25.3
Playing in a band or orchestra	13.2	2.0 (1.81)	6.3 (4.13)	Shout over 1 m	65.8 (10.52)	72.8 (11.13)	13.2
Other noisy leisure-time activities	9.9	4.3 (5.19)	5.8 (5.48)	Shout over 1 m	66.7 (10.53)	72.4 (12.06)	13.7

Note. HPDs: Hearing Protection Devices; L<sub>Aeq, w</sub>: Weekly noise exposure; L<sub>Aeq, l</sub>: Lifetime noise exposure; PMPs: Personal Music Players.



From Figure 5.3, it can be seen that attending nightclubs and music venues are mostly (63.4%) associated with a subject's maximum  $L_{Aeq,l}$ , followed by musical concerts or festivals (8.9%). The maximum  $L_{Aeq,l}$  ranged between 60.5 and 106.5 dBA with an average of 83.4 dBA (SD=8.70). During the activity with the maximum  $L_{Aeq,l}$ , 18.4% of the participants wear HPDs. No significant differences in the maximum  $L_{Aeq,l}$  or the use of HPDs during this activity was found according to age ( $p>0.05$ ). Regarding gender, a significant association with the maximum  $L_{Aeq,l}$  was found, whereby men had higher maximum  $L_{Aeq,l}$  (mean=85.0 dBA; SD=8.66) compared to women (mean=82.1 dBA; SD=8.47),  $t(514)=3.829$ ;  $p<0.001$ . No significant association was found between gender and the use of HPDs during the activity with the maximum  $L_{Aeq,l}$  according to a chi-squared test ( $p>0.05$ ).

Regarding the groups based on hearing status, independent samples t-tests revealed no significant differences in  $L_{Aeq,l}$  for each of the activities separately ( $p>0.05$ ). Likewise, no significant difference in maximum  $L_{Aeq,l}$  was found for those groups ( $p>0.05$ ). Furthermore, chi-square tests showed no significant association between the groups based on hearing status and the use of HPDs in each of the activities, separately, as well as during the activity with the maximum  $L_{Aeq,l}$  ( $p>0.05$ ).

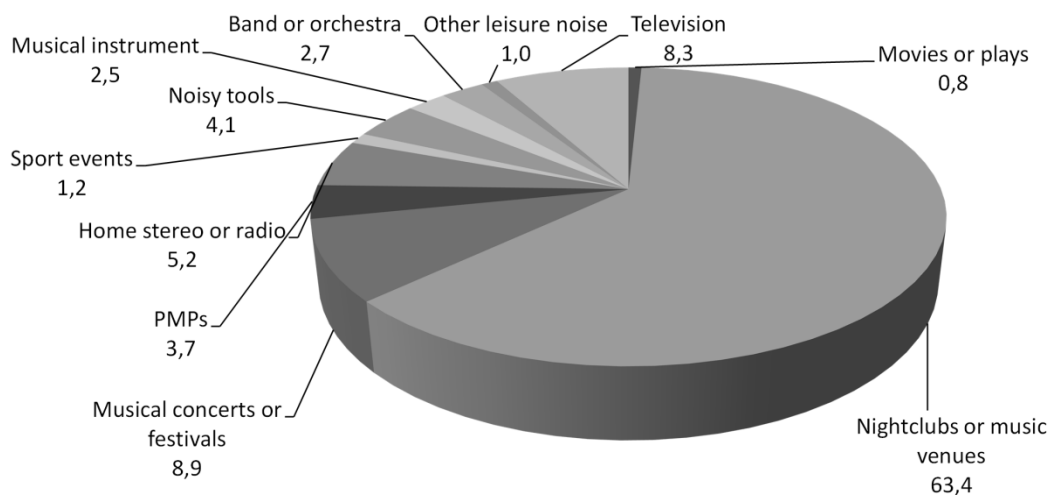


Figure 5.3 Proportions of activities to the maximum lifetime noise exposure (in %).

**Attitudes towards noise, hearing loss and HPDs.** Table 5.5 reflects the mean and standard deviations of the scores on subscales of the YANS and BAHPHL. Concerning the subscales of the YANS, the highest average score was found for the attitudes regarding daily noise, whereas the lowest average score was related to the attitudes intending to influence

the sound environment. For the subscales of BAHPHL, the lowest and highest average scores were respectively found for the severity of consequences of hearing loss and the barriers to preventive action. The score on the entire YANS did not show any differences according to age, though the score was significantly lower for women (mean=2.6; SD=0.47) compared to men (mean=2.9; SD=0.47),  $t(515)=5.492$ ;  $p<0.001$ . The score on the entire BAHPHL did not show any significant changes with both age and gender ( $p>0.05$ ).

Regarding the groups based on hearing status, no significant differences in the scores were found for the entire YANS and BAHPHL as well as each of their subscales ( $p>0.05$ ).

Table 5.5 For the YANS and BAHPHL, the mean, standard deviation and range of scores are reflected (n=517).

Questionnaire	Subscales	Mean	SD	Range
<b>YANS</b>	<i>Elements of youth culture</i>	2.6	0.67	1.25-4.75
	<i>Concentration in noisy environments</i>	2.9	0.92	1.00-5.00
	<i>Daily noise</i>	3.5	0.73	1.50-5.00
	<i>Intent to influence sound environment</i>	2.2	0.69	1.00-4.50
	<i>Entire YANS</i>	2.7	0.48	1.36-4.37
<b>BAHPHL</b>	<i>Susceptibility to hearing loss</i>	1.8	0.55	1.00-3.83
	<i>Severity of the consequences of hearing loss</i>	1.6	0.61	0.99-5.00
	<i>Benefits of preventive action</i>	1.7	0.57	1.00-3.67
	<i>Barriers to preventive action</i>	3.0	0.81	1.00-5.00
	<i>Behavioural intentions</i>	2.6	1.03	1.00-5.00
	<i>Social norms</i>	2.8	0.87	1.00-5.00
	<i>Self-efficacy</i>	2.7	0.76	1.00-5.00

### 5.1.3.3 Multivariate analysis

Finally, binary logistic regression was used to examine if the maximum  $L_{Aeq,l}$  and age in combination with several covariates are associated with a person's hearing status. The maximum  $L_{Aeq,l}$  was not significantly associated with hearing status in any of the multiple logistic regression models. On the other hand, each of the models showed that subjects were more likely to have subclinical hearing loss when they are older (Table 5.6). The covariates that were included in respectively model 2, 3 and 4 showed no significant association with a subject's hearing status.

Table 5.6 Relation of leisure time noise exposure, age and associated variables with groups based on hearing status: results of logistic regression models.

Variable	MODEL 1	MODEL 2	MODEL 3	MODEL 4
	(n=517)	(n=517)	(n=517)	(n=517)
	OR (95%CI)	OR (95%CI)	OR (95%CI)	OR (95%CI)
<b>L<sub>Aeq, max</sub></b>	1.01 (0.98 -1.04)	1.01 (0.98-1.04)	1.01 (0.98-1.04)	1.01 (0.98-1.04)
<b>Age</b>	<b>1.12 (1.05-1.20)*</b>	<b>1.10 (1.01-1.20)*</b>	<b>1.13 (1.05-1.21)*</b>	<b>1.12 (1.05-1.20)*</b>
<b>Gender</b>		1.00		
	-Male			
	-Female	0.90 (0.55-1.50)		
<b>Employment status</b>		1.00		
	-Not employed or student			
	-Employee	1.22 (0.64-2.31)		
<b>Wearing HPDs</b>			1.00	
	-No			
	-Yes		0.79 (0.41-1.51)	
<b>Attitudes total scores</b>				0.77 (0.45-1.34)
	-YANS			
	-BAHPHL			1.09 (0.60-1.99)

Note: OR: Odds Ratio; CI: Confidence Interval. \* indicates a significant result ( $p < 0.05$ ).

#### 5.1.4 Discussion

The present study evaluated the hearing status in a group of 517 Flemish young adults between 18 and 30 years. Results showed that pure-tone thresholds were within the normal range of hearing and both TEOAEs and DPOAEs were absent in a small proportion of the tested subjects. Hence, subjects could only be categorized into a group with normal hearing and subclinical hearing loss. These results are consistent with the studies of Mostafapour et al. (1998) and Williams, Carter, and Seeto (2015), who did not find a significant hearing loss in young adults. Other studies, however, reported that a substantial proportion of young adults have hearing loss due to noise exposure (Le Prell, Hensley, Campbell, Hall III, & Guire, 2011; Shargorodsky, Curhan, Curhan, et al., 2010). As suggested by Schlauch and Carney (2012), there are several methodological differences between studies, such as the definition of a normal-hearing individual as well as the quality of the hearing measurements that are used, which may lead to inconsistent results. In this respect, the present study used a stringent set of inclusion criteria and hearing acuity was based on an average of multiple thresholds estimates as well as TEOAE and DPOAE results (Schlauch & Carney, 2012; Tharpe & Bess, 1999).

The present study also evaluated the relation between a subject's hearing status and sociodemographic variables. Both the univariate and multivariate analysis showed that gender was not associated with hearing status. On the other hand, age was significantly associated with subclinical hearing loss in both the univariate and multivariate analyses. However, based on the well-known relation between age and hearing deterioration (International Organization for Standardization, 2000), we would not expect clinical age-related hearing changes in such a young age group. Besides, employment status was univariately associated with hearing status, whereby subclinical hearing loss was more present in subjects who were employed compared to unemployed subjects or students. However employment status was not associated with an increased risk of subclinical hearing loss according to the multivariate analysis. This might be explained by the fact that multivariate analyses take interdependencies between different variables into account. Employment status could be related with age, as subjects who were employed were older compared to the unemployed subjects or students in this study. The question may, therefore, rise whether the amount of noise exposure may be related to the age-related differences that were found.

Excessive exposure to noise has been repeatedly reported as a risk factor for hearing damage (Beach, Williams, et al., 2013; Lipscomb, 1969; Meyer-Bisch, 1996). The present study confirmed that the majority of the young adults in this study participate in several leisure activities, with a wide variation in attendance and equivalent noise levels per activity. In accordance with previous research, nightclubs and music venues were found to have an increased risk of high noise levels (Beach, Williams, et al., 2013; Dehnert et al., 2015; Keppler, Dhooge, et al., 2015b). Moreover, these activities yield the highest  $L_{Aeq, 1}$  in the majority of the subjects (63.4%). However, in accordance with previous research, no significant relations were found between hearing status and noise exposure (Dehnert et al., 2015; Lindeman et al., 1987; Mercier & Hohmann, 2002; Williams et al., 2015). A possible explanation for this result might be that the frequency of attendance in different leisure activities, and, therefore, noise exposure levels, did not show enough variation among the subjects in this age group. Indeed, no significant relation was found between age and subjects' maximum noise exposure levels. As was shown by previous research, teenagers tend to participate more in high-noise leisure activities such as attending night clubs when

they become older during the adolescence phase (Biassoni et al., 2014; Jokitulppo et al., 1997), while participation in these activities seems to decrease among subjects over 30 years of age (Beach, Gilliver, et al., 2013; Jokitulppo, 2003; Meyer-Bisch, 1996). Furthermore, it might be possible that exposure to leisure noise during this period of life is too short to cause sufficient hearing loss (Smith et al., 2000). The present study showed that the average total time young adults participated in several leisure activities is approximately 7 years (Table 5.4). The effects of noise exposure may thus become noticeable over the long term, since the effects of noise exposure on hearing are greatest during the first 10 to 15 years of exposure (American College of Occupational and Environmental Medicine, 2003).

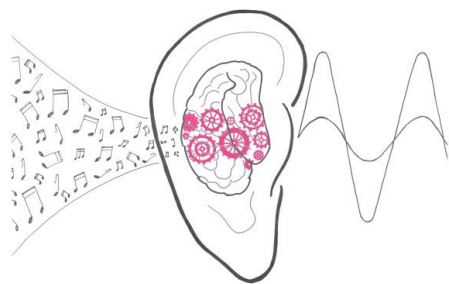
As a result, the consequences of excessive leisure noise exposure on hearing may not immediately be perceived by young adults or may not be experienced as serious enough (Keppler, Dhooge, et al., 2015a; Rawool & Colligon-Wayne, 2008). In the present study, no significant associations were found between a subject's hearing status and the attitudes towards noise, hearing loss and HPDs. In accordance to these results, we found that the majority of the subjects did not wear HPDs during leisure activities. This reflects the model of Widén (2013), which states that subjects without hearing-related symptoms are less likely to protect their hearing. The present study also did not find a relation between hearing status and the use of HPDs. It could be expected that the subjects who never wear HPDs during noisy leisure activities have a greater risk of (sub)clinical hearing loss compared to subjects who always wear HPDs. However, as the present study did not evaluate how long someone has been wearing HPDs, it is not possible to draw conclusions about the effectivity of wearing HPDs to protect hearing.

The results of the current study should be considered taking into account some limitations. First, convenience sampling was used, which might imply that the sample is not completely representative for the whole Flemish population of young adults. Nevertheless, it was ensured that an approximately equal sample of men and woman was recruited from the different regions in Flanders with a wide variation in age and professional status. Second, the estimation of leisure noise exposure might be affected by measurement errors, that is, the self-reported time of attendance to several leisure activities might be imprecise and no actual loudness measurements were performed to calculate the A-weighted equivalent levels. However, previous research showed that subjects can make a reasonable estimate of

the loudness of activities they participated in (Beach, Williams, & Gilliver, 2012a), which makes it possible to detect the activities with the highest risk of excessive noise levels. Third, TEOAEs and DPOAEs were evaluated in terms of their presence/absence, which might be insufficient to reveal significant relations. Therefore, using OAE-amplitudes with clear criteria would be useful in further research concerning the effects of leisure noise exposure on hearing. Finally, this study did not detect participants with clinical hearing loss according to both tonal audiometry and OAEs. Further research including such participants is necessary to further investigate the effects of leisure noise on hearing as well as the relation with their attitudes towards noise, hearing loss and HPDs.

In conclusion, the results of the present study showed no evidence of hearing loss in a large group of Flemish young adults between 18 and 30 years. Furthermore, no consistent relations were found between a subject's actual hearing status and leisure noise exposure, which in turn could lead to more non-protective behaviour. However, the effects of leisure noise may become noticeable over the long term as the results of this study revealed that the presence of subclinical hearing loss was associated with age. Longitudinal studies are needed to monitor the hearing status as well as to evaluate the long-term effects of noise exposure. Besides, preventive campaigns should further focus on self-experienced symptoms in order to make young adults aware of the harmful effects of excessive noise exposure.





## **CHAPTER 5**

### **Prevalence of noise-induced damage in Flemish young adults**

## **PART II**

### **Epidemiology and risk factors for tinnitus after leisure noise exposure in Flemish young adults**

Based on:

Degeest, S., Keppler, H., Corthals, P., Clays, E. (2017). Epidemiology and risk factors for tinnitus after leisure noise exposure in Flemish young adults. *International Journal of Audiology*, 56(2), 121-129.

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**Abstract**

**Purpose.** Young people regularly expose themselves to leisure noise and are at risk for acquiring tinnitus. This study examined the prevalence of leisure noise-induced tinnitus among Flemish young adults as well as the relation with sociodemographic factors, health-related variables and attitudes and beliefs towards noise.

**Method.** A self-administered questionnaire was used to evaluate the presence of noise-induced tinnitus, the amount of leisure noise and attitudes towards noise and hearing protection. 517 subjects between 18 and 30 years were included.

**Results.** Temporary and chronic tinnitus occurred in 68.5% and 6.4% of the sample, respectively. Chronic tinnitus was more prevalent in male subjects and associated with more hearing-related symptoms. Furthermore, subjects with chronic tinnitus were more aware of the risks of noise and the importance of hearing protection. Finally, higher levels of leisure noise were independently associated with chronic tinnitus.

**Conclusions.** Tinnitus is observed frequently in young adults. Results also indicate that persons with chronic tinnitus were exposed to a higher noise dose during their lives. Longitudinal studies may be useful to evaluate whether the experience of chronic tinnitus has led to behavioural changes. These findings further underpin the importance of educating youth about the risks of leisure noise exposure.

### 5.2.1 Introduction

Excessive noise levels are increasingly common in different aspects of daily activities (World Health Organization, 2015). Although noise exposure is often thought of as an occupational hazard, there is a growing concern about the risks of noise exposure during leisure activities, especially in teenagers and young adults. Visiting nightclubs, discotheques and live concerts are reported as the major sources of leisure noise among these young individuals (Beach, Williams, et al., 2013; Jokitulppo, 2003; Keppler, Dhooge, et al., 2015b; Smith et al., 2000). Additionally, high noise levels from personal music players (PMPs) are considered to be potentially harmful (Keppler, Dhooge, Maes, et al., 2010; Meyer-Bisch, 1996).

Exposure to excessive intensity levels can induce metabolic and mechanical changes in the organ of Corti (Talaska & Schacht, 2007), resulting in either temporary or permanent hearing threshold shifts (Hellström et al., 1998; Miller, 1974; Zhao et al., 2010). However, noise-induced hearing loss (NIHL) initially remains unnoticed, as speech understanding is at the beginning unaffected (Daniel, 2007). Furthermore, tinnitus is also a commonly reported symptom after noise exposure. In general, tinnitus can be defined as the perception of sounds without an external physical source (Møller, 2011c) and can also be temporary or chronic (Kaltenbach & Manz, 2011). Especially chronic tinnitus can result in comorbid distressing symptoms (Henry & Meikle, 2000) such as sleep disturbance, impaired concentration and communication, and difficulties during daily activities (Axelsson & Prasher, 2000; Fioretti et al., 2013; Martines et al., 2010).

Until now, the prevalence of noise-induced tinnitus (NIT) has been determined from several investigations conducted in different countries. The reported prevalence of temporary tinnitus varies between 15% and 75% for teenagers (Jokitulppo et al., 1997; Landälv, Malmström, & Widén, 2013; Widén & Erlandsson, 2004; Widén et al., 2009) and between 58% and 70% for young adults (Jokitulppo, 2003; Jokitulppo et al., 2006; Rosanowski et al., 2006). Chronic tinnitus is less prevalent than temporary tinnitus with a prevalence ranging between 3% and 9% for teenagers (Widén & Erlandsson, 2004; Widén et al., 2006; Widén et al., 2009) and between 5% and 10% for young adults (Jokitulppo et al., 2006; Rosanowski et al., 2006). In Flanders, there are known prevalence numbers for temporary and chronic tinnitus in a large group of teenagers and a group of university students (Gilles et al., 2012;

Gilles et al., 2013). Temporary tinnitus was reported by 74.9% and 89.5% of the teenagers and university students respectively, while the prevalence of chronic tinnitus ranged between 15% and 18% in both groups. An exploratory study of the prevalence and characteristics of tinnitus in Flemish young adults showed that the majority is exposed frequently to leisure noise, and that temporary tinnitus was experienced by 73.5% and chronic tinnitus by 6.6% (Degeest, Corthals, Vinck, & Keppler, 2014).

The abovementioned studies reveal that chronic tinnitus is less prevalent than temporary tinnitus in young people, and that reported rates of temporary tinnitus vary widely between studies. A possible reason may be attributed to discrepancies in the definition of temporary and chronic tinnitus in the various studies. More specifically most studies did not define the duration of temporary and chronic tinnitus which may have resulted in inconsistent reports of temporary versus chronic tinnitus by the survey respondents. Another reason for the discrepancy between studies might be related to the differences in the age groups studied and the fact that leisure habits, and therefore noise exposure levels, change as teenagers become young adults. Teenagers tend to participate more in high-noise leisure activities such as attending night clubs when they become older during the adolescence phase (Biassoni et al., 2014; Jokitulppo et al., 1997), while participation in these activities seems to decrease among subjects over 30 years of age (Beach, Gilliver, et al., 2013; Jokitulppo, 2003; Meyer-Bisch, 1996).

Understanding the prevalence of tinnitus is particularly important because previous research has shown that those who experience tinnitus and other hearing-related symptoms are more worried about their hearing and are more likely to use HPDs during noisy activities (Beach, Williams, & Gilliver, 2012b; Keppler, Dhooge, et al., 2015a; Widén & Erlandsson, 2004; Widén et al., 2006). In the current study, we have adopted the theoretical framework developed by Widén (2013) to explain young people's attitudes and behaviours towards leisure noise exposure. The model combines all the factors from the Theory of Planned Behaviour (TPB) (Ajzen, 1991); that is attitudes, subjective norms and perceived behavioural control, with the perceived benefits and barriers to modifying the behaviour and triggers to action from the Health Belief Model (HBM) (Rosenstock, 1974). Attitudes can be described as the tendency to respond positively or negatively towards a certain phenomenon. Subjective norms are the perceived social pressure to engage or not engage in a particular

behaviour (e.g. wearing HPDs), while perceived behavioural control refers to an individual's perception about the ease or difficulty of undertaking a specific behaviour. Perceived benefits and barriers of performing the behaviour can transform risk-taking behaviour into health-oriented behaviour, whereas triggers are certain factors which may lead to behavioural change (Rosenstock, 1974). In addition to the factors of the TPB and HBM, a risk perception factor was added, which deals with an individual's awareness of the risks of noise exposure (Widén, 2013). Triggers, such as tinnitus, are negatively correlated with attitudes, meaning that experiencing tinnitus after noise exposure leads to more anti-noise attitudes and more protective behaviour (Widén, 2013).

The main objective of this study was to examine the prevalence of temporary and chronic tinnitus in a group of Flemish young adults between 18 and 30 years, as well as to explore the association with baseline sociodemographic factors, health-related variables, noise exposure and attitudes and beliefs towards noise, hearing loss and HPDs using the theoretical framework outlined by Widén (2013). Not only will such information increase knowledge about the effects of leisure noise on the hearing of young adults, it can be useful to further optimize future preventive campaigns.

## **5.2.2 Method**

### **5.2.2.1 Study sample**

This study was a cross-sectional study using a self-administered questionnaire. A cohort of young adults between 18 and 30 years was recruited in Flanders, the northern region of Belgium. Within a variety of settings - Flemish companies, universities and public places (e.g. sports clubs and youth associations) - individuals were invited to participate in the study by distributing an invitation letter through email, online (school) platforms or posters. Individuals contacted the researchers and were then offered the ability to complete the questionnaire online or in paper form.

Based on a chronic tinnitus prevalence of 6.6% in young Flemish adults between 18 and 30 years from a pilot study (Degeest et al., 2014), power calculations revealed that a sample of 380 young adults was sufficient for determining the prevalence of chronic tinnitus with a precision of 5% at the  $\alpha=0.05$  significance level (Daniel, 1999). A total of 540 young adults participated in the study. However, since some participants did not complete the

questionnaire correctly, the responses of 517 young adults were further analyzed, i.e. a drop out of 4.3%. The final sample consists of 307 females and 210 males with an age range of 18 to 30 years (mean 23 years, SD 3.54). Completed surveys were returned by email (80.3%) or personally collected by the researchers (19.7%).

The study was approved by the Ethical Committee of Ghent University Hospital and was conducted in accordance with the ethical standards stipulated in the Helsinki declaration for research involving human subjects.

#### **5.2.2.2 Questionnaire data**

A questionnaire was designed based on available literature regarding leisure noise exposure and the assessment of NIT and NIHL (Jokitulppo et al., 2006; Keppler, 2010; Svensson et al., 2004; Widén et al., 2006). The preliminary version of the questionnaire was tested by means of a semi-structured interview-based assessment in a group of young adults between 18 and 30 years, who were not included in the study. After analyzing their responses, the clarity of some items and the adequacy of some response alternatives were adjusted.

The final questionnaire comprised 44 items in five sections. The first section included several sociodemographic variables. Participants were asked about their age, gender, professional status (employee, unemployed or student), health status and smoking habits.

The second section consisted of questions regarding subjective hearing status and medical history concerning ear-related disorders.

In the third section of the questionnaire, the amount of leisure noise exposure and the amount of time the respondent wore HPDs was recorded for several leisure activities that are common among young adults such as visiting nightclubs and playing musical instruments. In addition, the amount of occupational noise exposure was also recorded in order to control for as a possible confounding factor. Participants were asked how many times per year, month, week or day they attended each type of activity, the duration of their average visit to each of these (in hours), the total time of exposure to each activity (in years) as well as their estimation of loudness in terms of communicative effort. Five levels of loudness were considered: (1) level of a normal conversation, (2) level of a loud conversation, (3) level at which one must shout over one meter in order to be heard (e.g.

over table), (4) level at which one must shout over a near distance in order to be heard (e.g. someone less than an arm's length away), (5) level that makes communication impossible. These data were used to calculate a person's accumulated lifetime equivalent noise exposure per activity. The methods for calculation were adapted from Jokitulppo et al. (2006) and used in Keppler, Dhooge, et al. (2015b). First, the scale of loudness was transformed into A-weighted equivalent sound pressure levels ranging from 60 to 100 dBA for ratings of 1 to 5, respectively. Subsequently, the weekly equivalent noise exposure was calculated as  $L_{Aeq,w} = L_{Aeq} + 10 \log_{10}(T_w/T_0)$  where  $L_{Aeq}$  represented the A-weighted equivalent sound pressure levels from 60 to 100 dBA,  $T_w$  the time spent per week in hours and  $T_0$ , the 40-hours reference of a workweek. The lifetime equivalent noise exposure was then calculated as  $L_{Aeq,l} = L_{Aeq,w} + 10 \log_{10}(T_y)$  where  $L_{Aeq,w}$  reflected the weekly noise exposure and  $T_y$  the time of exposure in years.

The fourth section consisted of a Dutch modified version of the 'Youth Attitude to Noise Scale' (YANS) (Keppler, 2010; Widén et al., 2006) and a Dutch modified version of the 'Beliefs about Hearing Protection and Hearing Loss' (BAHPHL) (Keppler, 2010; Svensson et al., 2004). The YANS evaluated a subject's attitude towards noise and consisted of 19 items that were measured using a five-point Likert scale ranging from 'totally disagree' to 'totally agree'. A higher score on the YANS indicated a positive or pro-noise attitude representing an attitude where noise is seen as unproblematic. The 19 items were divided over four factors representing attitudes towards noise associated with elements of youth culture (factor 1: 8 items), the ability to concentrate in noisy environments (factor 2: 3 items), daily noises (factor 3: 4 items), and intent to influence the sound environment (factor 4: 4 items) (Widén et al., 2006). The quartiles of the scores on subscales of the YANS were used to categorize subjects' attitudes and beliefs into a negative (lower quartile) group, a neutral (two middle quartiles) group, and a positive (upper quartile) group, which respectively represents subjects with more anti-noise, neutral and pro-noise attitudes.

The BAHPHL instrument evaluated the attitudes towards hearing loss and HPDs and contained 24 items which can be divided over seven factors: susceptibility to hearing loss (factor 1: 6 items), severity of consequences of hearing loss (factor 2: 3 items), benefits of preventive action (factor 3: 3 items), barriers to preventive action (factor 4: 4 items), behavioural intentions (factor 5: 3 items), social norms (factor 6: 2 items), and self-efficacy

(factor 7: 3 items) (Svensson et al., 2004). Consistent with the YANS, the items were evaluated by a five-point Likert scale with higher scores corresponding to a more positive attitude, meaning that one does not care about the possible consequences of hearing loss and is unaware of the benefits of wearing HPDs.

The fifth and last part of the questionnaire included questions regarding the presence of tinnitus after leisure noise exposure and whether the tinnitus was temporary or chronic. Temporary tinnitus was defined as tinnitus disappearing within 72 hours after the exposure to leisure noise. If temporary tinnitus occurred after exposure to leisure noise, the section regarding the characteristics of temporary tinnitus had to be completed. In case of chronic tinnitus, respondents filled in the section pertaining to the characteristics of chronic tinnitus as well as a Dutch version of the Tinnitus Handicap Inventory (THI) (Newman, Jacobson, & Spitzer, 1996).

To ensure that the questionnaire was completed correctly by the subjects, instructions were provided at the beginning of the form as well as for each new section. All terminology regarding leisure noise, hearing and tinnitus was explained and appropriate examples were given.

### **5.2.2.3 Statistical analysis**

Statistical analysis was performed using SPSS version 21 (SPSS Inc. Chicago IL, USA). Descriptive parameters were established for the questionnaire outcomes and prevalence data for temporary and chronic tinnitus were calculated.

Based on the prevalence data of temporary and chronic tinnitus, three groups were created: (1) subjects without tinnitus; (2) subjects with temporary tinnitus; (3) subjects with chronic tinnitus. Subsequently, univariate analyses were performed to evaluate the relation of different variables with the presence of tinnitus. In case of continuous variables, a one-way analysis of variance (ANOVA) was conducted. After ANOVA, post-hoc Scheffé testing was performed when the threshold of significance was reached ( $p < 0.05$ ). To examine possible correlations between categorical variables, chi-square tests (3x2 tables) were performed. When the chi-squared test was significant, pairwise comparisons with Bonferroni corrections of the P-values were performed ( $\alpha = 0.05/3$ ) between the categories of interest (i.e.



temporary tinnitus versus chronic tinnitus, temporary tinnitus versus no tinnitus, and chronic tinnitus versus no tinnitus). If one or more cells had an expected count less than five, Fisher's exact test was used ( $p < 0.05$ ). In addition, a binary logistic regression model (enter method) was used to examine if the presence of chronic tinnitus is related to gender, age and lifetime noise exposure.

### 5.2.3 Results

#### 5.2.3.1 Prevalence and characteristics of tinnitus

The prevalence of temporary tinnitus in at least one ear was 68.5% (95% confidence interval (CI) [64.50%–72.50%]) and persisted for less than one hour after leisure noise exposure in the majority of the cases (58.4%). Chronic tinnitus was reported by 6.4% (95% CI [4.30%–8.50%]) of the subjects and was mostly present for one up to five years (48.5%). Both temporary and chronic tinnitus were mostly observed bilaterally as a continuous high-pitched pure tone.

#### 5.2.3.2 Univariate associations with the presence of tinnitus

**Baseline sociodemographic variables.** The relationship between the presence of tinnitus and the baseline sociodemographic variables is presented in Table 5.7. Chi-square tests revealed an overall significant association between gender and the three different tinnitus groups: chronic, temporary, and no tinnitus. However, Bonferroni corrected pairwise comparisons only showed a non-significant trend of more chronic tinnitus in the male subjects. No statistically significant relationship was found between the presence of tinnitus and age, employment status or smoking habits ( $p > 0.05$ ).

**Health-related variables.** Table 5.7 also shows the relationship between health-related variables and the presence of tinnitus. Chi-square tests revealed a significant association with the subjective experience of hearing loss, speech understanding in different listening situations and the occurrence of dullness ( $p < 0.05$ ). Bonferroni corrected pairwise associations revealed that subjects with chronic tinnitus have poorer subjective hearing and more difficulty understanding speech in different listening situations compared to subject groups with temporary tinnitus and subjects without tinnitus. Furthermore, both subjects with temporary and chronic tinnitus indicated significantly more symptoms of dullness after leisure noise exposure compared to subjects without tinnitus.

Table 5.7 Description of the baseline sociodemographics and health-related variables in 517 participants.

Variable		Total sample (n=517)	Tinnitus			Univariate test	
			No tinnitus	Temporary	Chronic	Test statistic	P
Age	mean (SD)	22.8 (3.54)	23.0 (3.59)	22.8 (3.48)	23.0 (3.96)	F=0.256	0.775
Gender	% (n)					<b><math>\chi^2=9.193</math></b>	<b>0.010</b>
-Male		40.6 (210)	47.7 (62)	36.4 (129)	57.6 (19)		
-Female		59.4 (307)	52.3 (68)	63.6 (225)	42.4 (14)		
Employment status	% (n)					$\chi^2=0.156$	0.925
-Employee		39.5 (204)	39.2 (51)	36.4 (141)	36.4 (12)		
-Not employed or Student		60.5 (313)	60.8 (79)	60.2 (213)	63.6 (21)		
Smoking	% (n)					$\chi^2=3.965$	0.138
-Yes		25.1 (130)	19.2 (25)	26.6 (94)	33.3 (11)		
-No		74.9 (387)	80.8 (105)	73.4 (260)	66.7 (22)		
Chronic illness	% (n)					$\chi^2=4.459$	0.108
-Yes		14.3 (74)	18.5 (24)	12.1 (43)	21.2 (7)		
-No		85.7 (443)	81.5 (106)	87.9 (311)	78.8 (26)		
Subjective hearing loss	% (n)					<b><math>\chi^2=34.190</math></b>	<b>&lt;0.001</b>
-Yes		9.1 (47)	3.8 (5) <sup>†</sup>	8.5 (30) <sup>‡</sup>	36.4 (12) <sup>††</sup>		
-No		90.9 (470)	96.2 (125)	91.5 (324)	63.6 (21)		
Speech understanding in quiet	% (n)					<b><math>\chi^2=10.859</math></b>	<b>0.004</b>
-Good		91.3 (472)	91.5 (119) <sup>†</sup>	92.7 (328) <sup>‡</sup>	75.8 (25) <sup>††</sup>		
-Poor		8.7 (45)	8.5 (11)	7.3 (26)	24.2 (8)		
Speech understanding in quiet with several persons	% (n)					<b><math>\chi^2=12.136</math></b>	<b>0.002</b>
-Good		71.8 (371)	74.6 (97) <sup>†</sup>	73.2 (259) <sup>‡</sup>	45.5 (15) <sup>††</sup>		
-Poor		28.2 (146)	25.4 (33)	26.8 (95)	54.5 (18)		
Speech understanding in noise	% (n)					<b><math>\chi^2=6.495</math></b>	<b>0.039</b>
-Good		27.7 (143)	36.2 (47) <sup>*</sup>	25.1 (89) <sup>*</sup>	21.2 (7)		
-Poor		72.3 (374)	63.8 (83)	74.9 (265)	78.8 (26)		
Dullness	% (n)					<b><math>\chi^2=43.430</math></b>	<b>&lt;0.001</b>
-Yes		44.3 (229)	20.8 (27) <sup>*†</sup>	50.6 (179) <sup>*</sup>	69.7 (23) <sup>†</sup>		
-No		55.7 (288)	79.2 (103)	49.4 (175)	30.3 (10)		

Note. Significant values are in bold. Bonferroni corrected significant difference between group with temporary tinnitus and group without tinnitus<sup>\*</sup>; between group with chronic tinnitus and group without tinnitus<sup>†</sup>, and between group with temporary tinnitus and group with chronic tinnitus<sup>‡</sup>.

**Attitudes towards noise, hearing loss and HPDs.** The relationship between the presence of tinnitus and the scores on the YANS and BAHPHL are shown in Table 5.8. A significant difference between the groups was found for the score on the entire YANS as well as for the scores on the factors related to youth culture, the ability to concentrate in noisy environments and the intent to influence the sound environment respectively. More specifically, a trend towards lower scores (i.e., negative attitudes towards noise) was observed in subjects with chronic tinnitus compared to subjects with temporary tinnitus and subjects without tinnitus, except for the factor related to the ability to concentrate in noisy environments. Significant lower scores were found in subjects with chronic tinnitus compared to subjects without tinnitus for the factor related to 'youth culture'. Furthermore, subjects with temporary tinnitus scored lower on the items related to the 'ability to concentrate in noisy environments' compared to subjects with chronic tinnitus and subjects without tinnitus. Regarding the factor related to the intent to influence the sound environment and the entire YANS, significant differences were found between subjects with temporary tinnitus and subjects without tinnitus, whereby subjects with temporary tinnitus scored lower on the items of both factors. Depending on the scores on the different subscales of the YANS, a distinction was made between a negative, neutral and positive attitude towards noise for each group (Figure 5.4). In accordance with the ANOVA results, it can be seen from Figure 5.4 that subjects with chronic tinnitus tend to have more neutral or negative attitudes towards noise compared to subjects with temporary tinnitus or subjects without tinnitus, except for the factor related to the ability to concentrate in noisy environments.

Regarding the BAHPHL, a significant difference in the scores was found between the groups for the factors related to susceptibility to hearing loss, severity of consequences of hearing loss, benefits of preventive action, behavioural intentions and self-efficacy (Table 5.8). Consistent with the YANS outcome, a trend towards more negative attitudes in the subjects with chronic tinnitus was observed. Significant differences were found between subjects without tinnitus and those with temporary and chronic tinnitus for the factor related to susceptibility of hearing loss, i.e., those with tinnitus scored lower on items related to susceptibility, indicating that they felt more susceptible to hearing loss than those without tinnitus. The scores for the factor 'severity of hearing loss' were significantly lower in

subjects with temporary tinnitus compared to subjects without tinnitus, which indicates that subjects with temporary tinnitus were more aware of the severity of hearing loss. Regarding the factors related to 'benefits of preventive action' and 'behavioural intentions', significant differences in the scores were found between each group, whereby the scores were lowest for the subjects with chronic tinnitus, indicating that they perceived more benefits of undertaking preventive actions and that they were more willing to perform a given behaviour. Finally, subjects with chronic tinnitus scored significantly lower on the factor related to 'self-efficacy' compared to both subject groups with temporary tinnitus and subjects without tinnitus, indicating that subjects with chronic tinnitus were more convinced that they can execute the behaviour necessary to protect their hearing.

Furthermore,  $\chi^2$  tests showed a significant association between the presence of tinnitus and the use of HPDs ( $p < 0.05$ ), with pairwise associations with Bonferroni correction revealing that subjects with chronic tinnitus wear HPDs significantly more often than subjects with temporary tinnitus or subjects without tinnitus (Table 5.8).

Table 5.8 Description of the attitudes towards noise, hearing loss and HPDs and the use of HPDs in 517 participants.

Variable	Total sample (n=517)	Tinnitus			Univariate test		
		No tinnitus	Temporary	Chronic	Test statistic	P	
<b>YANS</b>	mean (SD)						
-Elements of youth culture	2.6 (0.67)	2.7 (0.71) <sup>†</sup>	2.5 (0.64)	2.3 (0.70) <sup>†</sup>	<b>F=5.021</b>	<b>0.007</b>	
-Concentration in noisy environments	2.9 (0.92)	3.1 (0.95) <sup>*</sup>	2.8 (0.90) <sup>*‡</sup>	3.4 (0.79) <sup>‡</sup>	<b>F=8.504</b>	<b>&lt;0.001</b>	
-Daily noise	3.5 (0.73)	3.5 (0.76)	3.4 (0.71)	3.4 (0.84)	F=0.677	0.509	
-Intent to influence sound environment	2.2 (0.69)	2.3 (0.75) <sup>*</sup>	2.1 (0.65) <sup>*</sup>	2.1 (0.68)	<b>F=3.693</b>	<b>0.026</b>	
-Entire YANS	2.7 (0.48)	2.8 (0.54) <sup>*</sup>	2.7 (0.45) <sup>*</sup>	2.6 (0.50)	<b>F=5.786</b>	<b>0.003</b>	
<b>BAHPHL</b>	mean (SD)						
-Susceptibility to hearing loss	1.8 (0.55)	2.0 (0.62) <sup>*†</sup>	1.7 (0.51) <sup>*</sup>	1.5 (0.49) <sup>†</sup>	<b>F=13.567</b>	<b>&lt;0.001</b>	
-Severity of the consequences of hearing loss	1.6 (0.61)	1.7 (0.76) <sup>*</sup>	1.5 (0.54) <sup>*</sup>	1.7 (0.63)	<b>F=5.575</b>	<b>0.004</b>	
-Benefits of preventive action	1.7 (0.57)	1.9 (0.62) <sup>*†</sup>	1.7 (0.54) <sup>*‡</sup>	1.4 (0.51) <sup>†‡</sup>	<b>F=9.931</b>	<b>&lt;0.001</b>	
-Barriers to preventive action	3.0 (0.81)	3.1 (0.79)	3.0 (0.81)	2.9 (0.96)	F=0.686	0.504	
-Behavioural intentions	2.6 (1.03)	2.9 (1.07) <sup>*†</sup>	2.5 (0.97) <sup>*‡</sup>	1.7 (0.90) <sup>†‡</sup>	<b>F=18.013</b>	<b>&lt;0.001</b>	
-Social norms	2.8 (0.87)	2.8 (0.93)	2.8 (0.86)	3.0 (0.76)	F=0.998	0.369	
-Self-efficacy	2.7 (0.76)	2.8 (0.80) <sup>†</sup>	2.7 (0.75) <sup>‡</sup>	2.4 (0.68) <sup>†‡</sup>	<b>F=3.453</b>	<b>0.032</b>	
<b>Wearing HPDs</b>							
-Yes	% (n)	34.8 (180)	28.5 (37) <sup>†</sup>	32.8 (116) <sup>‡</sup>	81.8 (27) <sup>†‡</sup>	<b>χ<sup>2</sup>=35.091</b>	<b>&lt;0.001</b>
-No		65.2 (337)	71.5 (93)	67.2 (238)	18.2 (6)		

Note. Significant values are in bold. Post-hoc Sheffé or Bonferroni corrected significant difference between group with temporary tinnitus and group without tinnitus<sup>\*</sup>; between group with chronic tinnitus and group without tinnitus<sup>†</sup>, and between group with temporary tinnitus and group with chronic tinnitus<sup>‡</sup>.  
YANS, Youth Attitudes to Noise Scale; BAHPHL, Beliefs About Hearing Protection and Hearing Loss; HPDs, Hearing Protection Devices.

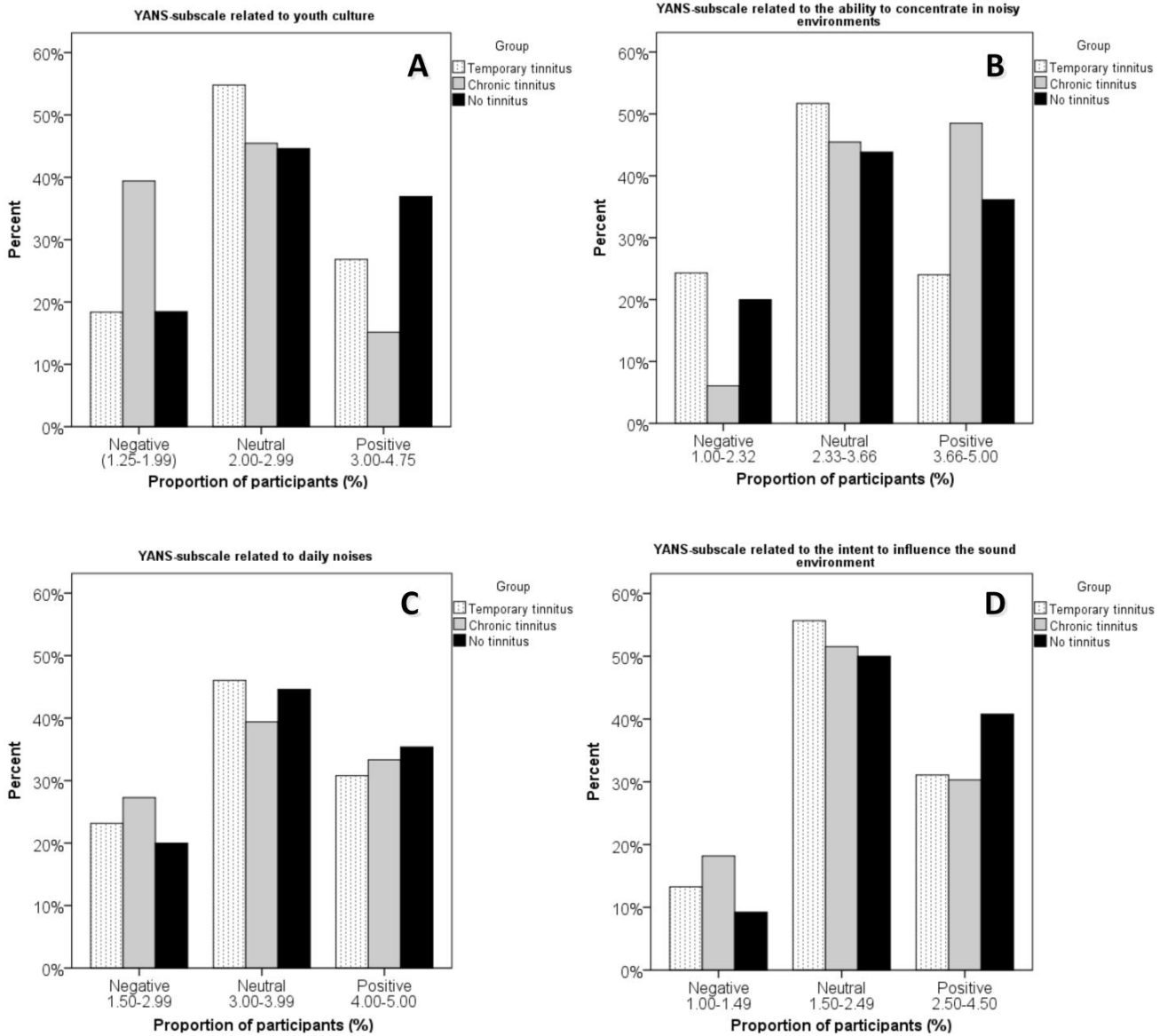


Figure 5.4 For the presence of tinnitus, the percentage of participants that fell into the different attitudes of the YANS-subscale related to youth culture (a), the ability to concentrate in noisy environments (b), daily noises (c), and the intent to influence the sound environment (d). For each subscale, the range of scores of attitudes are reflected on the horizontal axis.

**Leisure noise exposure.** The relation between the lifetime noise level (dBA) of various leisure activities and the presence of tinnitus is shown in Table 5.9. Watching movies or plays, visiting nightclubs or music venues, attending musical concerts or festivals and listening to PMPs through headphones were attended the most by the participants in the present study. However, the calculated weekly and lifetime noise levels were highest for nightclubs and music venues. For each of the leisure activities, no significant difference in lifetime noise exposure was found between the groups, except for nightclubs and music venues. Post-hoc Scheffé tests revealed a significant higher lifetime noise level for nightclubs and music venues for subjects with chronic tinnitus (mean= 85.8 dBA; SD=9.93) compared to subjects with temporary tinnitus (mean=81.1 dBA; SD=10.46) and subjects without tinnitus (mean=79.8 dBA; SD=10.09).

In addition to leisure noise exposure, 15.3% of the participants reported occupational noise exposure, though no significant relation was found between lifetime occupational noise exposure and the presence of tinnitus.

### **5.2.3.3 Multivariate analysis**

Finally, binary logistic regression was used to examine if gender, age and a person's lifetime noise exposure level can predict the presence of chronic tinnitus. Two groups were considered: the first group consisted of the subjects with chronic tinnitus, while the second group consisted of the subjects without tinnitus and those with temporary tinnitus, since they currently do not experience chronic symptoms. The lifetime noise level is based on the exposure during visits to nightclubs and music venues since univariate analyses showed that only these activities were significantly related to tinnitus.

The results of the binary logistic regression showed that subjects with a higher lifetime noise level for nightclubs and music venues were significantly more likely to experience chronic tinnitus (OR per dB noise level=1.05; 95% CI=1.01 to 1.10). The odds for chronic tinnitus increased to 1.17 (95% CI=1.03-1.33) for every 3 dB increase in lifetime noise exposure at nightclubs and music venues (Table 5.10).

Table 5.9 Percentage of subjects' attendance, mean number of years participating in each activity as well as the resulting mean A-weighted equivalent SPLs in dBA (n=517).

Activity	Attendance (%)	Years of exposure mean (SD)	L <sub>Aeq, w</sub> (dBA)	L <sub>Aeq, l</sub> (dBA)	Univariate test	
					Test statistic	P
Watching movies or plays	95.6	10.3 (4.50)	50.0 (8.49)	59.6 (8.64)	F=0.115	0.891
Visiting nightclubs or music venues	92.5	6.3 (3.24)	73.7 (10.54)	81.1 (10.41)	<b>F=3.990</b>	<b>0.019</b>
Attending musical concerts or festivals	85.5	5.6 (3.11)	64.4 (8.88)	71.2 (9.33)	F=1.430	0.240
Listening to PMPs through headphones	84.5	7.1 (3.60)	58.2 (12.19)	66.0 (12.79)	F=1.103	0.333
Listening to a home stereo or radio	69.4	10.0 (6.55)	58.2 (8.82)	67.1 (9.39)	F=0.221	0.802
Attending sport events	49.7	7.5 (5.02)	51.7 (9.73)	59.3 (11.07)	F=0.161	0.851
Using noisy tools	28.2	5.7 (4.74)	61.7(13.67)	67.8 (13.72)	F=1.450	0.238
Practicing a musical instrument	26.7	9.6 (4.85)	56.4 (11.66)	65.2 (11.85)	F=1.924	0.150
Occupational noise	15.3	3.5 (2.86)	68.5 (12.41)	72.3 (13.37)	F=1.615	0.206
Playing in a band or orchestra	13.2	6.3 (4.13)	65.8 (10.52)	72.8 (11.13)	F=0.260	0.772
Other noisy leisure-time activities	9.9	5.8 (5.48)	66.7 (10.53)	72.4 (12.06)	F=0.207	0.814

Note. Univariate test refers to the association between the lifetime noise exposure per activity (L<sub>Aeq, l</sub>) and the presence of tinnitus (no tinnitus, temporary tinnitus, chronic tinnitus) using one-way ANOVA. Significant values are in bold.

L<sub>Aeq, w</sub>: Weekly noise exposure; L<sub>Aeq, l</sub>: Lifetime noise exposure; PMPs: Personal Music Players.

Table 5.10 Logistic regression model explaining the presence of chronic tinnitus.

Variable	Reference	B-value	OR	95% CI for OR: lower	95% CI for OR: upper	P
Age	n.a.	0.002	1.00	0.89	1.13	0.980
Gender	Female	0.734	2.08	0.94	4.60	0.069
Cumulative noise exposure (dB)	n.a.	0.052	1.05	1.01	1.10	<b>0.018</b>

Note. Significant values are in bold. Nagelkerke R<sup>2</sup> was 0.062 meaning that 6.2% of the variance was explained by the model.

n.a., not applicable; OR, odds ratio



#### 5.2.4 Discussion

In this study, an overall prevalence of 68.5% of temporary tinnitus was observed, a result consistent with previous research (Degeest et al., 2014; Jokitulppo et al., 2006; Rosanowski et al., 2006). The present study also showed that 6.4% of the young adults already reported chronic tinnitus in at least one ear. However, one study in Flanders reported a higher prevalence of chronic tinnitus (14.8%) in a group of young adults between 19-26 years (Gilles et al., 2012). Although this study sample is quite similar to the present study regarding age, the difference in prevalence might be due to the fact that Gilles et al. (2012) only included students, who presumably participated regularly in leisure activities. Furthermore, it might be that these students were exposed to higher intensity levels and therefore were at risk for acquiring tinnitus. However, no information regarding the participation at leisure activities nor the noise exposure was provided by Gilles et al. (2012). There was also a discrepancy in the definition of temporary and chronic tinnitus between both studies, which might also have led to differences in the results. Gilles et al. (2012) did not define the duration of temporary tinnitus and only used a yes-no question to evaluate the presence of chronic tinnitus, whereby participants possibly may have misclassified temporary tinnitus as chronic tinnitus, which in turn may have led to a higher reported prevalence of chronic tinnitus.

Univariate analyses of the sociodemographic data showed a trend to a higher prevalence of chronic tinnitus in men. A higher prevalence of chronic tinnitus in the general male population has been reported already by previous studies, in which it was suggested that men are more exposed to both occupational and leisure noise, and thus have a greater risk of acquiring tinnitus (Baigi et al., 2011). In the present study, the lifetime noise level for nightclubs and music venues was also higher for men compared to women. In contrast, no differences in the presence of chronic tinnitus were found for age. This might be explained by the fact that the frequency of attendance in different leisure activities did not significantly change among the subjects in this age group, while this might be the case for children and teenagers or older adults (Jokitulppo, 2003; Widén & Erlandsson, 2004). In accordance with previous research, no clear relation was found between tinnitus and employment status (Nondahl et al., 2012) or smoking habits (Mahboubi, Oliaei, Kiumehr, Dwabe, & Djalilian, 2013).

Univariate analyses with health-related variables revealed that subjects with chronic tinnitus experience significantly more hearing-related symptoms, such as subjective hearing loss, the occurrence of dullness and difficulties with understanding speech in different listening situations, compared to subjects with temporary tinnitus and subjects without tinnitus. These results suggest that subjects with chronic tinnitus might already have more hearing-related symptoms as a result of their noise exposure. Hence, they might be more worried about the effects of loud noise, leading to a more anti-noise attitude (Bohlin & Erlandsson, 2007; Widén & Erlandsson, 2004).

The present study evaluated the relation between the presence of tinnitus and a subject's attitude towards noise, hearing loss and HPDs using the YANS and the BAHPHL questionnaire. It was found that subjects with chronic tinnitus tend to hold significantly more anti-noise attitudes than those without chronic tinnitus. Subjects with temporary tinnitus also showed a more anti-noise attitude than subjects without tinnitus, but less than subjects with chronic tinnitus. However, it should be noted that for factor two of the YANS (the ability to concentrate in noisy environments), a more pro-noise attitude was found for subjects with chronic tinnitus. This finding may possibly be explained by the fact that persons with chronic tinnitus often profit from environmental sounds as maskers for their tinnitus (Widén, 2013). Based on the BAHPHL, it was found that those with temporary or chronic tinnitus were more likely to feel susceptible to hearing loss than those without tinnitus. Furthermore, subjects with chronic tinnitus indicated significantly more benefits of preventive actions and were more likely to change their behaviour towards wearing HPDs compared to subjects without tinnitus. However, the benefits and behavioural intentions towards HPDs indicated by the subjects with temporary tinnitus were still less than those reporting chronic tinnitus, which is consistent with the finding that subjects with chronic tinnitus wear significantly more hearing protection during leisure-noise activities.

Overall, these results are in accordance with the model of Widén (2013), which stated that self-experienced symptoms may serve as a trigger to a more anti-noise attitude, which may lead to preventive behaviour. Indeed, a significant decrease in leisure noise exposure and in several subscales of the YANS and BAHPHL after educating youth about the impact of noise on hearing and the corresponding symptoms was found by Keppler, Dhooge, Degeest, and Vinck (2015). In Flanders, many educational campaigns have been conducted in recent years

in order to emphasize the harmful effects of loud music on hearing, which might also have led to more antinoise attitudes and acceptance of HPDs. However, it should be mentioned that, in the present study, not every participant with chronic tinnitus wore HPDs. Further research investigating potential variables leading to non-use of HPDs in this specific group of tinnitus subjects would be useful.

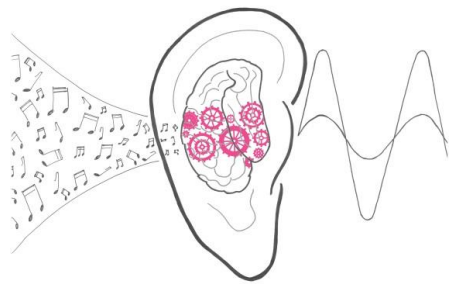
Despite the high rate of reported hearing-related symptoms that were found in this study (74.9%), the majority of the subjects still expose themselves to noise during leisure activities. In accordance with other research, nightclubs were found to be one of the major sources of high leisure noise levels in young adults (Beach, Williams, et al., 2013; Jokitulppo, 2003; Smith et al., 2000), which presents risks for acquiring tinnitus. A significant univariate relation was found between the presence of tinnitus and a person's lifetime noise level for nightclubs and music venues, with subjects suffering from chronic tinnitus having significantly higher lifetime noise levels as compared to subjects without tinnitus. No significant differences in lifetime noise levels were found between subjects with temporary tinnitus and subjects without tinnitus. The results of the logistic regression analysis showed that a higher lifetime noise level for nightclubs and music venues was independently associated with chronic tinnitus. This finding can be explained by the well-known fact that the risk of damage to hearing increases with the intensity and exposure time (Hellström et al., 1998). As defined by NIOSH, hazardous noise is a sound that exceeds 85 dB over a typical 8-hour day (Centers for Disease Control and Prevention/NIOSH, 1998) and can cause significant damage to the auditory system. A mean lifetime noise level for nightclubs and music venues of 85.8 dB was found for subjects indicating chronic tinnitus.

A possible limitation of this study is that convenience sampling was used, which might imply that the sample is not completely representative for the Flemish population of young adults. Nevertheless, a power analysis based on a pilot study was conducted to determine an adequate sample size to estimate the population prevalence with good precision (Naing, Winn, & Rusli, 2006) and, moreover, it was ensured that men and women were recruited from different regions in Flanders with a wide variation in age and employment status.

In conclusion, the results of this study confirmed that temporary NIT is observed frequently in young adults in Flanders. Furthermore, chronic tinnitus was also reported by 6.4% of the

participants. Results also indicate that persons with chronic tinnitus were exposed to higher noise levels from attendance at nightclubs and music venues. They also had a more anti-noise attitude and wore more hearing protection compared to subjects with temporary tinnitus and subjects without tinnitus. These results underpin the importance of educating young adults about the risks of loud noise exposure during leisure activities, however, with special attention to tinnitus as a sign of overexposure. It should be underlined that temporary tinnitus can be an indication of early hearing damage and can evolve into chronic tinnitus. Since tinnitus is a symptom that can be clearly noticed after exposure to leisure noise, this might serve as a trigger towards more awareness of the risks of leisure noise and the importance of HPDs.





## CHAPTER 6

### Audiological assessment in tinnitus subjects

## PART I

### The characteristics of tinnitus after leisure noise exposure in young adults

Based on:

Degeest S, Corthals P, Vinck B, Keppler H. (2014). Prevalence and characteristics of tinnitus after leisure noise exposure in young adults. *Noise and Health*, 16(68), 26-33

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**Abstract**

**Purpose.** The main goal of this study was to assess the prevalence and characteristics of tinnitus among students after exposure to leisure noise. In addition, the effects of tinnitus on otoacoustic emissions (OAEs) in participants suffering from chronic tinnitus were evaluated.

**Method.** The study consisted of two parts. First, a questionnaire regarding leisure noise exposure and tinnitus was completed. Second, the hearing status of the subjects suffering from chronic tinnitus was evaluated and compared with a matched control group (CG). Furthermore, the psychoacoustical characteristics of their tinnitus in the chronic tinnitus group (TG) were established.

**Results.** The questionnaire was answered by 151 respondents. Seven persons suffering from chronic tinnitus were examined further in the second part of the study. Temporary tinnitus was observed in 73.5% of the respondents after leisure noise exposure and 6.6% experienced chronic tinnitus. Temporary and chronic tinnitus had similar characteristics, as established by the questionnaire. The amplitude of transient evoked otoacoustic emissions and distortion product otoacoustic emissions was reduced and the amount of efferent suppression was smaller in the TG as compared with the CG.

**Conclusions.** Tinnitus induced by leisure noise is observed frequently in young adults. The characteristics of tinnitus cannot predict whether it will have a temporary or rather a chronic nature. In subjects suffering from tinnitus, subclinical damage that cannot be detected by audiometry can be demonstrated by measuring OAEs. These findings underpin the importance of educating youth about the risks of noise exposure during leisure activities.



### 6.1.1 Introduction

It is well-known that excessive noise exposure can lead to temporary, as well as chronic ear damage (Talaska & Schacht, 2007). Occupational noise is known as potentially harmful. Furthermore, exposure from leisure activities, especially in young adults, is a cause of concern. Smith et al. (2000) reported that 18.8% of 18-to 25-year-olds had been exposed to noise from leisure activities. Therefore, young adults are at risk of ear damage, such as hearing loss (HL) or tinnitus.

The overall number of teenagers and young adults who experienced temporary tinnitus after visiting discotheques, music concerts or listening to music through headphones ranges between 20% and 80% (Jokitulppo et al., 1997; Rosanowski et al., 2006; Widén & Erlandsson, 2004; Zocoli, Morata, Marques, & Corteletti, 2009). Besides temporary tinnitus, Widén and Erlandsson (2004) found that 8.7% of their sample of young adults experienced chronic tinnitus. Despite the usefulness of these studies including hearing education programs, there are often differences in the prevalence of tinnitus. These differences can be due to a discrepancy in the definition of temporary and chronic tinnitus used in the questionnaires. In general, temporary tinnitus does usually not last longer than a few seconds to a maximum of a couple of days, while chronic tinnitus lasts from months to years (Kaltenbach & Manz, 2011). Both temporary and chronic tinnitus are generally characterized as tonal (Axelsson & Sandh, 1985; Chermak & Dengerink, 1987) with a high pitch (Axelsson & Sandh, 1985; Loeb & Smith, 1967; Nageris et al., 2010).

Studies on the effects of leisure noise exposure on hearing thresholds revealed inconsistent results. Serra et al. (2005) examined the effects of leisure noise exposure on hearing of young adults over a period of 4 years. A threshold shift, exceeding 30 dB HL in some subjects, was found in the 3rd year of the study and continued in the 4th year. In contrast, Lindeman et al. (1987) found no deteriorated hearing thresholds. However, conventional pure-tone audiometry only detect HL as soon as a considerable amount of hair cells is damaged (Daniel, 2007). This suggests that conventional audiometry is insensitive to detect subtle noise-induced cochlear changes.

Exposure to leisure noise is reported as a key factor in causing outer hair cell (OHC) damage in young people (Rosanowski et al., 2006). Moreover, OHC dysfunction is also reported as a

significant factor in the generation of tinnitus (Granjeiro et al., 2008). Damage to the cochlear OHCs can be objectively documented using otoacoustic emissions (OAEs) (Marshall et al., 2001). OAEs are low-level sounds reflecting the non-linear active processes in the cochlea. Transient evoked otoacoustic emissions (TEOAEs) and distortion product otoacoustic emissions (DPOAEs) are responses following a brief stimulus or following acoustic stimulation with two pure tones presented simultaneously, respectively. One study investigated the influence of leisure noise on hair cell activity in a group of medical students by measuring the TEOAEs (Rosanowski et al., 2006). They reported decreased TEOAE amplitudes and reproducibility with increased disco-visits. To the best of our knowledge, literature concerning the effects of noise-induced tinnitus (NIT) on OAEs is rare. In contrast, many studies investigated the effects of tinnitus on OAEs in subjects with tinnitus caused by Meniere's disease, head injury, sudden deafness or idiopathic tinnitus. Overall, those studies reported smaller TEOAE amplitudes (Granjeiro et al., 2008; McKee & Stephens, 1992; Paglialonga et al., 2010; Thabet, 2009) or DPOAE amplitudes (Granjeiro et al., 2008; Ozimek et al., 2006; Paglialonga et al., 2010) in normal hearing subjects with tinnitus when compared to subjects without tinnitus.

The medial olivocochlear system (MOC), which has an inhibitory effect on the OHCs, is also suggested as a factor in the origin of tinnitus (Jastreboff, 1990). Some studies reported a reduced suppression effect of the MOC system in subjects with tinnitus (Ceranic, Prasher, Raglan, & Luxon, 1998; Paglialonga et al., 2010). Recently however, Geven, de Kleine, Free, and van Dijk (2011) found an equal amount of suppression in subjects with and without tinnitus. Furthermore, Attias, Bresloff, and Furman (1996) showed increased TEOAEs in the presence of contralateral acoustic stimulation (CAS) in subjects with NIT.

In light of the increasing concern about leisure noise exposure, this study assessed the effects of leisure noise in a group of young adults in Flanders. The main goal was to assess the prevalence and characteristics of temporary and chronic tinnitus after exposure to leisure noise. In addition, the influence of tinnitus induced by leisure noise on hair cell activity was examined by measuring TEOAEs, DPOAEs and efferent suppression (ES) of TEOAEs in the subjects reporting chronic tinnitus.

### 6.1.2 Methods

The study consisted of two parts (Figure 6.1). First, a questionnaire was distributed to assess the prevalence and characteristics of temporary and chronic tinnitus. Second, the hearing status and the psychoacoustical characteristics of tinnitus were evaluated in subjects reporting chronic tinnitus.

The questionnaire was distributed online on several forums and student applications during 1 month. The responses of 151 young adults which consists of 100 females and 51 males with age range of 18-27 years (mean 23.2 years, SD 3.26 years), were further analyzed.

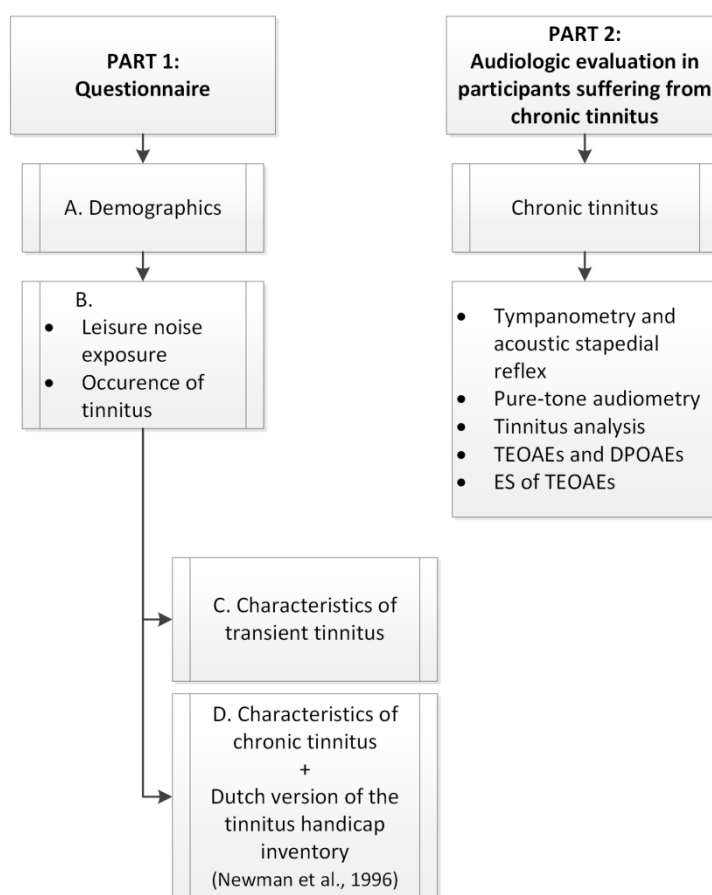


Figure 6.1 Schematic overview of the present study.

In the second part of the study, respondents who had indicated chronic tinnitus were asked to undergo further audiologic investigations. Seven (4 females, 3 males) respondents with chronic tinnitus were agreed to participate. The hearing status was evaluated during a single session by otoscopic evaluation, admittance measures, pure-tone audiometry and OAEs. Subsequently, a tinnitus analysis was performed. A control group (CG), matching the group

with chronic tinnitus (TG) by age and gender was established. All control subjects had normal hearing, defined as hearing thresholds equal to or better than 20 dB HL at octave step frequencies from 0.25 to 8.0 kHz and half octave frequencies 3.0 and 6.0 kHz, together with normal middle ear function.

#### **6.1.2.1 Part 1: Questionnaire**

A questionnaire was designed containing questions about leisure noise exposure and the experience of tinnitus. After a try out on 30 other subjects ranging in age from 18 to 30 years, the clarity of some items and the adequacy of some response alternatives were adjusted.

The questionnaire comprised of 44 items which consisted of four sections. The first section addressed demographic issues as well as subjective hearing status and medical history concerning ear-related disorders. The second section included questions regarding the amount of leisure noise exposure per week or month at music events, i.e. festivals, music concerts, discotheques and parties. Furthermore, the amount of time the respondent was wearing hearing protector devices during these activities was registered. Subsequently, the presence of tinnitus after exposure to leisure noise and whether the tinnitus was temporary or chronic was evaluated.

Temporary tinnitus was defined as tinnitus disappearing within 72 hours. If temporary tinnitus occurred after exposure to leisure noise, the third section regarding the characteristics of tinnitus had to be completed. In case of chronic tinnitus, respondents filled in section four of the questionnaire, which consisted of questions on the characteristics of tinnitus and a Dutch version of the tinnitus handicap inventory (THI) (Newman et al., 1996).

To ensure that the questionnaire was completed correctly by the subjects, instructions were provided at the beginning of the questionnaire as well as at each new section. All terminology regarding leisure noise, hearing and tinnitus was explained and appropriate examples were given.

#### **6.1.2.2 Part 2: Audiological evaluation in subjects with chronic tinnitus**

**Admittance measurements.** A 226 Hz tympanometry was performed with an 85 dB sound pressure level (SPL) probe tone. Ipsilateral and contralateral acoustic stapedial reflex

thresholds were measured at 1.0 kHz, as well as contralateral reflex threshold using broadband noise (Tymptstar, Grason-Stadler Inc.). A type A tympanogram and normal acoustic stapedial reflex thresholds were conditions to participate in the further audiological evaluation.

**Audiometry.** Pure-tone audiometry was performed using the modified Hughson-Westlake method for air conduction thresholds at conventional octave frequencies from 0.25 to 8.0 kHz and half octave frequencies 3.0 and 6.0 kHz using an Interacoustics AC-40 audiometer. Pure-tone average (PTA) was calculated as the average air conduction hearing thresholds at 0.5, 1.0 and 2.0 kHz.

Subjects were categorized as having a noise-induced threshold shift (NITS) according to the definition of Niskar et al. (2001) i.e. on the basis of three audiometric criteria for at least 1 ear. First, thresholds at 0.5 and 1.0 kHz had to be equal to or better than 15 dB HL. Second, the maximum threshold at 3.0, 4.0, or 6.0 kHz had to be at least 15 dB worse than the maximum threshold obtained at 0.5 or 1.0 kHz. Third, the threshold at 8.0 kHz had to be at least 10 dB better than the maximum threshold at 3.0, 4.0, or 6.0 kHz.

**Otoacoustic emissions.** TEOAEs, DPOAEs and TEOAEs with CAS were measured using the DPOAE probe (ILO 292 USB II module with ILOv6 software; Otodynamics Ltd., Hatfield, UK). The probe was calibrated before each measurement using the 1 cc calibration cavity provided by the manufacturer.

The non-linear differential stimulus paradigm was used for TEOAE measurements. Rectangular pulses of 80  $\mu$ s at a rate of 50 clicks/s were delivered at an intensity of  $80 \pm 2$  dB peak equivalent sound pressure level (peSPL). Registration of TEOAEs was terminated after 260 accepted sweeps with a noise rejection setting of 4 mPa. Emissions and noise amplitudes were calculated in half octave-frequency bands centered at 1.0, 1.5, 2.0, 3.0 and 4.0 kHz using ad hoc software. A probe stability of 90% or more was needed, and TEOAEs were considered present if the signal-to-noise ratio (SNR) was at least 3 dB in each half-octave frequency band.

DPOAEs were measured with primary tone level combinations of L1/L2 = 65/55 dB SPL. The f1/f2 ratio was 1.22, with f2 ranging from 0.841 to 8.0 kHz at eight points per octave. A noise

artefact rejection level of 6 mPa was used and the whole frequency range was looped until the noise amplitude fell below  $-5$  dB SPL at individual frequencies. DPOAEs were considered present if the SNR at all individual frequencies were at least 3 dB. Emission and noise amplitude were averaged for half-octave frequency bands with center frequencies 1.0, 1.5, 2.0, 3.0, 4.0, 6.0 and 8.0 kHz.

TEOAEs with CAS were measured using TEOAEs in linear mode with and without CAS at 60 dB peSPL. CAS of continuous white noise was presented at 60 dB peSPL. Clicks were presented in alternating blocks of 10 seconds without and with CAS stored in memory 1 and 2, respectively. A total of 260 sweeps were obtained and the noise rejection level was 4 mPa. Only TEOAEs with SNR of at least 3 dB in the condition without CAS were further analyzed. The amount of ES was calculated as the difference in TEOAE amplitude (in dB) with and without CAS in half-octave frequency bands centered around frequencies 1.0, 1.5, 2.0, 3.0 and 4.0 kHz.

**Tinnitus analysis.** Tinnitus was analyzed using the same equipment that was used for pure-tone audiometry. In addition, a HDA 200 phone (Sennheiser, Inc., Wedemark, Germany) was used for assessment of high-frequency ( $>8.0$  kHz) tinnitus. The tinnitus analysis consisted of (1) tinnitus pitch matching, (2) tinnitus loudness matching, (3) determining the minimum masking levels (MMLs) and (4) the residual inhibition (RI) following masking.

Before pitch matching, participants indicated whether their tinnitus was tonal or noise-like. Tinnitus pitch matching consisted of a two – alternative forced choice procedure and a test for octave confusion (Vernon & Meikle, 2003).

Loudness matching was done at the frequency determined by pitch matching. First, the hearing threshold at this frequency was obtained according to the modified Hughson-Westlake method. Second, the sound or noise intensity was increased in 1 dB steps until the subject reported that the stimulus was as loud as the tinnitus. The intensity of the loudness match was expressed in dB sensation level (SL).

The MML, i.e. the lowest level at which a white noise can mask the tinnitus, was determined. First the subjects' hearing threshold for the white noise was measured. Subsequently, the

noise level was raised in 1 dB increments until the subject reported that the tinnitus had become inaudible. The corresponding sound level was defined as the MML and was recorded in dB SL.

To determine the RI, white noise was presented during 1 minute at an intensity 10 dB above the MML (Vernon & Meikle, 2003). After 1 minute, the subject had to report whether the tinnitus had changed. Four classes of RI were considered: (1) Positive, tinnitus disappeared completely; (2) partial positive, tinnitus reduced; (3) rebound, tinnitus increased; (4) negative, tinnitus remained unchanged.

### **6.1.2.3 Data analysis**

Statistical analysis was performed using SPSS version 19 (SPSS Inc. Chicago IL, USA)). Descriptive parameters were established for the questionnaire outcomes. In addition, chi-square was calculated ( $p < 0.05$ ) to evaluate the relation between occurrence of tinnitus and the frequency and length of exposure to leisure noise. A chi-squared test was also used to evaluate whether the occurrence of tinnitus differed in subjects who always wore hearing protection as opposed to subjects who never wore hearing protection devices. If one or more cells had an expected count less than five, Fisher's exact test was used ( $p < 0.05$ ). The results of the second part of the study were analyzed to establish descriptive parameters. Furthermore, a Mann-Whitney U test ( $p < 0.05$ ) was used to evaluate whether the amplitude of TEOAEs and DPOAEs, and the amount of ES differed significantly between the TG and the CG.

## **6.1.3 Results**

### **6.1.3.1 Part 1: Questionnaire**

Temporary tinnitus in one or both ears was reported by 111 (73.5%) respondents and persisted for less than 1 h in the majority of the cases. 10 subjects (6.6%) indicated chronic tinnitus that had been present for either less than 1 year (in 4 out of 10 cases) or for one up to 5 years (in 6 out of 10 cases).

In Figure 6.2, an overview of the characteristics of temporary and chronic tinnitus is given. Both temporary and chronic tinnitus were mostly observed bilaterally as a continuous pure tone with a high pitch. The THI documents the impact of tinnitus on daily functioning in

persons with chronic tinnitus. In 4 cases (out of 10) a slight (0-16) impact was found. A mild (18-36) to moderate (38-56) impact was found in 4 (out of 10) and 2 cases (out of 10), respectively.

A majority of the respondents was frequently exposed to leisure noise. Weekly noise exposure was reported by 27.9% and 35.8% reported leisure noise on a monthly basis. 36.4% reported an exposure of less than once a month. Further, the majority of respondents (70.9%) had spent 3 up to 6 hours at a music event while 24.5% were exposed for 1 up to 3 hours and 4.6% for over 6 hours. No statistically significant relationship was found between the occurrence of tinnitus and the frequency of visiting music events ( $p>0.05$ ). Nevertheless, tinnitus was observed more often in respondents who spent more time (3 hours or more) at a music event. However, this effect was not statistically significant ( $p>0.05$ ).

Hearing protection was always worn by 9 respondents (6.0%) and never by 89 respondents (58.9%). Tinnitus was observed by 67 individuals (75.3%) who never and by six persons (66.7%) who always wear hearing protection. The Fisher's exact test was used, leading to the conclusion that there was no statistically significant relationship between the occurrence of tinnitus and the frequency of wearing hearing protectors ( $p>0.05$ ).



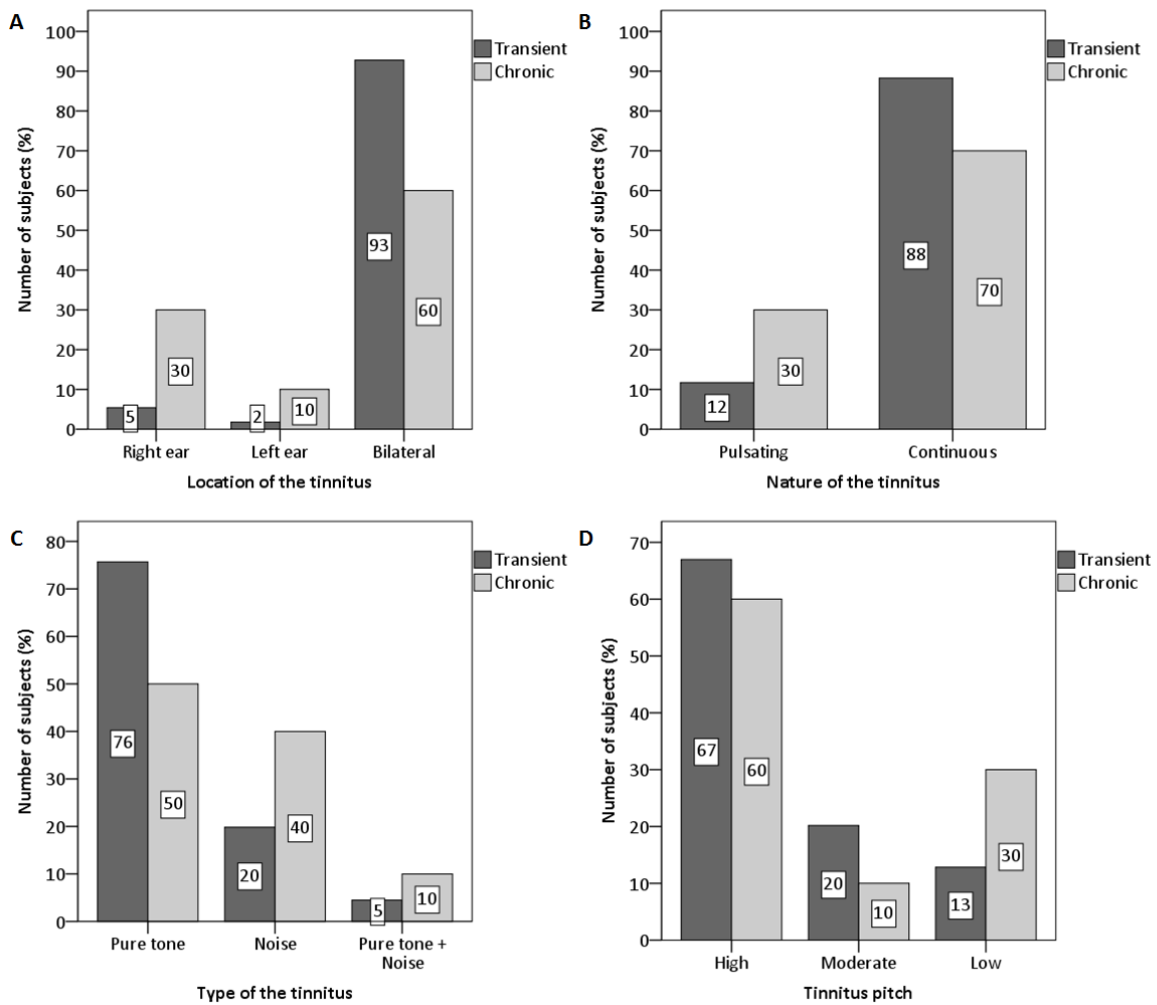


Figure 6.2 Overview of the characteristics of temporary versus chronic tinnitus: (a) The localization of the tinnitus, (b) the nature of tinnitus, (c) the type of tinnitus and (d) the pitch of the tinnitus.

### 6.1.3.2 Part 2: Audiologic evaluation in subjects with chronic tinnitus

Seven (out of 10) persons with chronic tinnitus participated in further audiological investigations.

The psychoacoustic characteristics of chronic tinnitus were evaluated by means of a tinnitus analysis. Tinnitus was experienced bilaterally in 4 subjects (out of 7) and unilaterally in 3 subjects (out of 7). A mean pitch of 6.0 kHz (SD 6.01 Hz; 0.75-16 kHz) was found. The mean loudness was 7.6 dB SL (SD 6.35; 1-22 dB SL) and the mean MML was 12.7 dB HL (SD 6.75; 1-21 dB HL). RI was partially positive in 3 (out of 7) and negative in 2 (out of 7) subjects with tinnitus. A rebound effect was found in 2 subjects with tinnitus (out of 7).

All subjects with chronic tinnitus had a PTA better than 20 dB HL. However, 3 subjects (out of 7) met the NITS criteria. NITS were in all subjects unilateral at 6.0 kHz. A Mann-Whitney U test showed a statistically significant difference in hearing threshold at 1 kHz between the tinnitus and the CG ( $U=26.50$ ,  $p>0.05$ ). For TEOAEs and DPOAEs, it can be seen in Figures 6.3 and 6.4 that the mean amplitudes in the TG were lower, compared to the CG. Differences in TEOAE amplitude were statistically significant at 1.0 kHz ( $U=24.50$ ),  $p<0.05$ ) and 4.0 kHz ( $U=11.00$ ,  $p<0.05$ ). The amplitude of DPOAEs showed a statistically significant difference at 1.5 kHz ( $U=21.00$ ,  $p<0.01$ ). Figure 6.5 shows that ES was less in the TG as compared to the CG. However, this was not statistically significant.

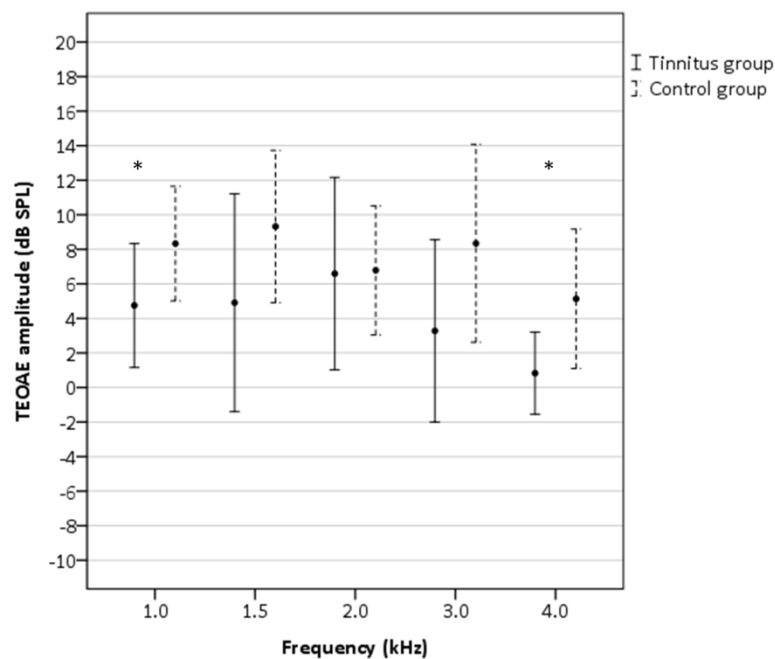


Figure 6.3 TEOAE amplitudes in dB sound pressure level for subjects with tinnitus (solid line) and the control group (dashed line): Mean  $\pm$  one standard deviation. \* $p<0.05$

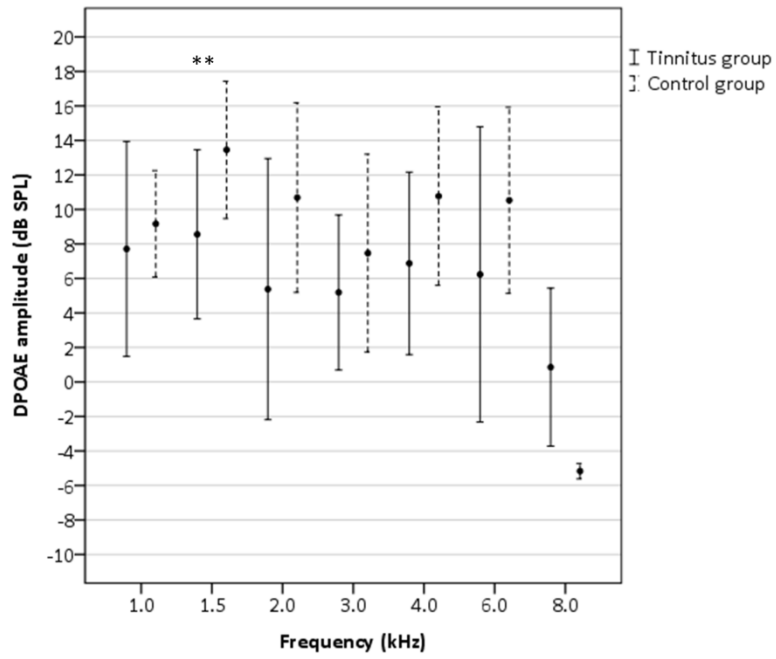


Figure 6.4 DPOAE amplitudes in dB sound pressure level for subjects with tinnitus (solid line) and the control group (dashed line): Mean  $\pm$  one standard deviation. \*\* $p < 0.01$

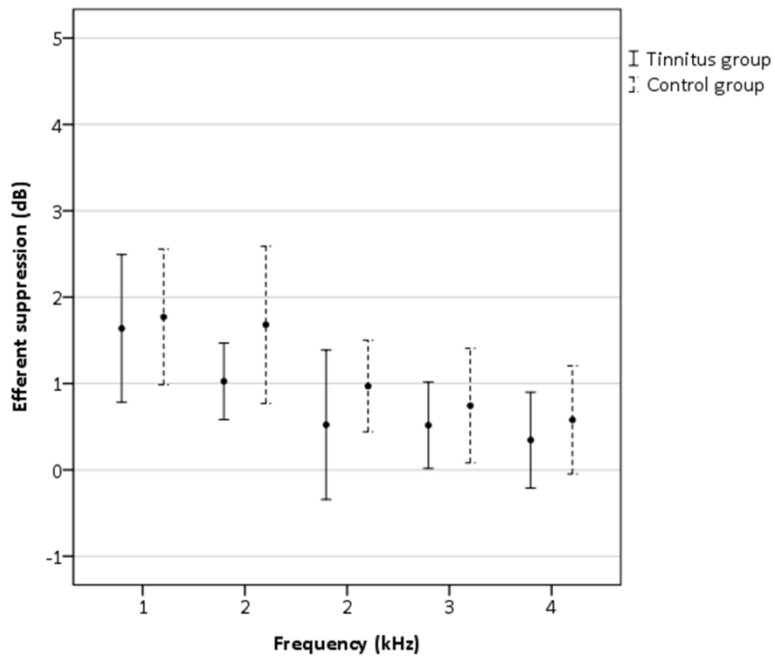


Figure 6.5 ES (in dB) for subjects with tinnitus (solid line) and the control group (dashed line): Mean  $\pm$  one standard deviation.

#### 6.1.4 Discussion

The prevalence of temporary tinnitus after exposure to leisure noise in the present study (73.5%) is in agreement with other studies on noise exposure in young adults (Chung, Des Roches, Meunier, & Eavey, 2005; Jokitulppo et al., 1997; Zocoli et al., 2009). However, one study reported a much lower prevalence of 22% which can be explained by a different definition of temporary tinnitus, i.e. 24 hours or longer (Widén & Erlandsson, 2004). These authors also reported the prevalence of chronic tinnitus (8.7%), which is in agreement with the prevalence found in the present study.

Although there was no significant relation between experiencing tinnitus and the frequency of visiting music events on weekly or monthly basis, this study confirmed that many young adults expose themselves frequently to loud music during leisure activities. More respondents experience tinnitus as the length of exposure exceeded the average of 3 hours. Both findings can be explained by the well-known fact that the risk of damage to hearing increases with the intensity and exposure time (Hellström et al., 1998). As defined by NIOSH, hazardous noise is a sound that exceeds 85 dB over a typical 8-hour day (Centers for Disease Control and Prevention/NIOSH, 1998) and can cause temporary or permanent effects on hearing. In the study of Serra et al. (2005), the equivalent A-weighted sound levels in discotheques were measured and ranged from 104 dBA to 112 dBA. Exposure to such high intensities implies risk for acquiring temporary or chronic tinnitus every time adolescents expose themselves to loud music.

There was no statistical relation between the use of hearing protection and experiencing tinnitus. The number of subjects in this study who always wore hearing protection was very small, while the majority of subjects never wore hearing protection. The unequal distribution of these two groups makes it difficult to compare the risk of acquiring tinnitus. The results of the current study may nevertheless indicate that the use of hearing protection can reduce the risk of acquiring tinnitus when exposed to leisure noise since they reduce the sound intensity.

Many studies have examined the characteristics of tinnitus. The majority of those studies have focused on chronic tinnitus that was attributed to a variety of causes (Cahani, Paul, & Shahr, 1983; Savastano, 2004). Publications addressing the characteristics of chronic

tinnitus induced by noise generally deal with tinnitus induced by occupational noise or noise in military service (Axelsson & Sandh, 1985; Nageris et al., 2010). They reported NIT as being tonal, with a high pitch between 4.0 kHz and 8.0 kHz. Few studies have investigated the characteristics of temporary tinnitus induced by a short exposure to noise. Here the outcome was that tinnitus generally is experienced as a continuous tonal sound with a pitch distributed over the mid- and high frequency range (Chermak & Dengerink, 1987; Loeb & Smith, 1967). To the best of our knowledge, there are no publications available addressing the characteristics of temporary and chronic tinnitus induced by leisure noise. In the present study, the characteristics of both temporary and chronic tinnitus induced by leisure noise were documented by means of a questionnaire. In the majority of the subjects, temporary and chronic tinnitus were subjectively experienced as tonal with a high pitch. The subjective experience of persons with chronic tinnitus is in agreement with the psychoacoustic measurements. This finding suggests that the characteristics of tinnitus observed after exposure to leisure noise cannot predict whether the tinnitus will be temporary or chronic. Nevertheless, experiencing temporary tinnitus after leisure noise exposure can be an important warning signal of early noise-induced damage to hearing.

THI indicated that for the majority of subjects with chronic tinnitus, it had a slight to moderate impact, which means that the tinnitus can be heard in a quiet environment, but can easily be masked by environmental sounds or easily be forgotten in the course of activities (Newman et al., 1996). Tinnitus had a lesser impact in the subjects who did not agree to participate in the further investigation. This could suggest that persons who observe a greater impact of tinnitus on daily functioning are more likely to seek help for their problem. However, the sample of subjects with chronic tinnitus was rather small in the present study and further research in a large population of young adults is needed to thoroughly document the characteristics and impact of chronic tinnitus induced by leisure noise exposure on the quality of life.

The results of the audiometric measurements showed PTAs equal or better than 20 dB HL in all subjects with chronic tinnitus. Three subjects met the NITS criteria. The amplitudes of TEOAEs and DPOAEs were reduced and the amount of ES was less in the TG as compared to the CG. It has been suggested that a decrease in OHC function could result in tinnitus before a shift in hearing threshold is seen (Ami et al., 2008).

However, significant differences between TG and CG were found only at 1.0 kHz and 4.0 kHz for TEOAEs and at 1.5 kHz for DPOAEs. The significant differences on the lowest of the frequencies (1.0 and 1.5 kHz) could probably be explained by the significant difference in hearing thresholds between the TG and CG at 1.0 kHz. Furthermore, the results might be influenced by the criteria used to determine present emissions as well as the small sample size of subjects with chronic tinnitus. Measuring OAEs in a larger sample of subjects with chronic tinnitus is needed. Nevertheless, these results suggest that TEOAEs and DPOAEs can be used as a useful tool to distinguish between normal hearing subjects with and without tinnitus induced by leisure noise. This outcome also corroborates the conclusions of Granjeiro et al. (2008) namely that OHC dysfunction may be important in the generation of tinnitus.

As far as ES is concerned, the amount was less in subjects with tinnitus as compared with the control subjects. These results are in agreement with the data reported by Ceranic et al. (1998) and Paglialonga et al. (2010). However, the difference in ES between both groups in the current study was not statistically significant. Since the sample of subjects whose OAEs were obtained was very small, the results should be interpreted with caution. Nevertheless, the effect of NIT on OAEs and ES and its clinical utility merits further investigation.

### **6.1.5 Conclusion**

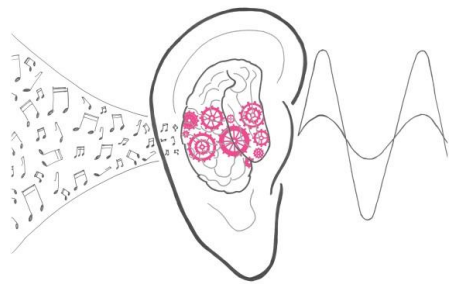
The present study showed that temporary tinnitus after exposure to leisure noise occurred frequently among young adults (in 73.5%). Furthermore, chronic tinnitus was reported by some participants (in 6.6%). No predictors were found among the characteristics of tinnitus allowing to infer whether tinnitus will be temporary or chronic.

In subjects with chronic tinnitus, the amplitudes of TEOAEs and DPOAEs were reduced and the amount of ES was less as compared to the CG, indicating subclinical damage and a possible role of the OHC in the generation of tinnitus induced by leisure noise. The clinical utility of OAEs and ES in subjects with tinnitus induced by leisure noise needs further research.

As an overall conclusion, it is very important to educate youth about the risks of noise exposure during leisure activities and the early symptoms of hearing damage.

### **Acknowledgments**

The authors would like to thank Kimberly De Wispelaere and Elien Verhaeghe for their contribution to this investigation and assistance in recruiting and testing of subjects.



## CHAPTER 6

### Audiological assessment in tinnitus subjects

## PART II

### The impact of tinnitus characteristics and associated variables on tinnitus-related handicap

Based on:

Degeest, S., Corthals, P., Dhooge, I., & Keppler, H. (2016). The impact of tinnitus characteristics and associated variables on tinnitus-related handicap. *The Journal of Laryngology & Otology*, 130(1), 25-31.

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**Abstract**

**Purpose.** This study aimed to determine the characteristics of tinnitus and tinnitus-related variables and explore their possible relationship with tinnitus-related handicap.

**Methods.** Eighty-one patients with chronic tinnitus were included. The study protocol measured hearing status, tinnitus pitch, loudness, maskability and loudness discomfort levels. All patients filled in the Tinnitus Sample Case History Questionnaire, the Hyperacusis Questionnaire and the Tinnitus Handicap Inventory. The relationship of each variable with the Tinnitus Handicap Inventory score was evaluated by univariate and multivariate analyses.

**Results.** Five univariates were associated with the Tinnitus Handicap Inventory score: loudness discomfort level, subjective tinnitus loudness, tinnitus awareness, noise intolerance and Hyperacusis Questionnaire score. Multiple regression analysis showed that the Hyperacusis Questionnaire score and tinnitus awareness were independently associated with the Tinnitus Handicap Inventory score.

**Conclusion.** Hyperacusis and tinnitus awareness were independently associated with the Tinnitus Handicap Inventory score. Questionnaires on tinnitus and hyperacusis are especially suited to providing additional insight into tinnitus-related handicap and are therefore useful for evaluating tinnitus patients.

### 6.2.1 Introduction

Tinnitus can be defined as the perception of sound without an external physical source (Møller, 2011c). The prevalence of tinnitus increases with age (Shargorodsky, Curhan, & Farwell, 2010; Sindhusake, Golding, et al., 2003) with a maximum prevalence of 14.3 per cent in individuals aged between 60 and 69 years (Sindhusake, Golding, et al., 2003). Most persons suffering from chronic tinnitus do not seek help to manage their problem (Henry, Dennis, et al., 2005). Nevertheless, tinnitus has a significant impact on the quality of life of up to 5 per cent of the adult population (Coles, 1984; Nondahl et al., 2002). Sleep disturbance and difficulties in performing daily activities are often reported (Fioretti et al., 2013; Henry & Meikle, 2000; Martines et al., 2010).

Tinnitus assessment generally consists of a medical and audiological evaluation aimed at objectivizing the subjective complaint and searching for common tinnitus causes (Kleinjung, 2011; Snow, 2004). Questions are asked to establish characteristics, such as tinnitus type, location and onset, and psychoacoustic measurements of tinnitus pitch, loudness and maskability are performed (Henry & Meikle, 2000; Henry, Zaugg, & Schechter, 2005). Several studies, however, have reported minimal or even absent relationships between the tinnitus characteristics and its perceived severity (Figueiredo, Rates, Azevedo, Oliveira, & Navarro, 2010; Granjeiro, Kehrle, de Oliveira, Sampaio, & de Oliveira, 2013; Hiller & Goebel, 1999; Karatas & Deniz, 2012; Martines et al., 2010; Meikle, Vernon, & Johnson, 1984).

Some authors have reported that factors other than the audiological characteristics of tinnitus are important for explaining differences in perceived tinnitus severity among patients (Hiller & Goebel, 2006; Milerová et al., 2013; Ooms et al., 2012). Some studies have reported an association between tinnitus severity and the degree of hearing loss (Axelsson & Ringdahl, 1989; Hiller & Goebel, 2006, 2007; Mazurek, Olze, Haupt, & Szczepek, 2010). It has also been suggested that sociodemographic factors such as sex and advanced age can influence tinnitus severity (Hiller & Goebel, 2006; Milerová et al., 2013; Schlee et al., 2011). A higher degree of distress was also reported in tinnitus patients with associated hyperacusis (Fioretti et al., 2013; Hiller & Goebel, 2006; Schecklmann, Landgrebe, Langguth, & Group, 2014). Although hyperacusis is often associated with tinnitus (Goldstein & Shulman, 1995)

there has been little research into the impact of coexisting tinnitus and hyperacusis on tinnitus severity.

In summary, existing studies show inconsistency regarding which variables relate to the perceived impact of tinnitus. This may be due to the use of different methods to assess tinnitus and different outcome instruments to measure the impact of tinnitus. Furthermore, many studies did not include regression analysis, which is a very useful way of exploring relationships between variables (Hoekstra et al., 2014).

The present study, therefore, measured the (psychoacoustic) characteristics of tinnitus and tinnitus-related variables using current audiological assessment methods and questionnaires in a group of patients with chronic tinnitus (Henry & Meikle, 2000; Snow, 2004). It also explored by regression analysis whether these characteristics and variables independently affect tinnitus-related handicap.

## **6.2.2 Methods**

### **6.2.2.1 Participants**

This study was conducted at the Department of Otolaryngology, Ghent University Hospital, Belgium. All participants were patients older than 18 years who presented with subjective non-pulsatile tinnitus that had existed for at least 3 months. The study was approved by the local Ethical Committee, and all participants gave informed consent.

### **6.2.2.2 Procedures**

A medical history was obtained from all patients and all underwent otological examination. Hearing status was subsequently evaluated by tympanometry and pure-tone audiometry and psychophysical measurements of tinnitus pitch and loudness, tinnitus maskability and loudness discomfort levels were performed. All measurements were conducted in a double-walled, sound-attenuated booth. Furthermore, all patients completed three self-reported questionnaires. The Tinnitus Sample Case History Questionnaire, the Hyperacusis Questionnaire and the Tinnitus Handicap Inventory were administered to verify tinnitus-related variables, hyperacusis and tinnitus-related handicap, respectively (Khalifa et al., 2002; Langguth et al., 2007; Newman et al., 1996).

All procedures contributing to this work complied with the ethical standards of the relevant national and institutional guidelines on human experimentation and with the Helsinki Declaration of 1975, as revised in 2008.

### **6.2.2.3 Audiological evaluation**

**Tympanometry.** All patients were subjected to 226-Hz tympanometry with an 85-dB sound pressure level probe tone (Tympstar; Grason-Stadler, Eden Prairie, Minnesota, USA). Type A tympanograms were obtained for all ears, indicating normal middle-ear status.

**Audiometry.** Pure-tone audiometry was performed using the modified Hughson–Westlake method. Air conduction thresholds were determined at octave frequencies from 0.25 to 8.0 kHz and at the half-octave frequencies 3.0 and 6.0 kHz, and bone conduction thresholds were determined at octave frequencies from 0.25 to 4.0 kHz (Personal computer based audiometer, Equinox 2.0 with TDH39 headphones, Interacoustics, Assen, Denmark). The pure tone average (PTA<sub>1.0,2.0,4.0</sub> kHz) was calculated for air conduction as the average of air conduction thresholds at 1.0, 2.0 and 4.0 kHz.

**Psychoacoustic measurements of tinnitus.** Tinnitus was evaluated using the same equipment as used for pure-tone audiometry. TDH39 headphones (Interacoustics) were used for all measurements. In addition, an HAD 200 phone (Sennheiser, Wedemark, Germany) was used to assess high-frequency (i.e. greater than 8.0 kHz) tinnitus. Tinnitus analysis consisted of (1) tinnitus pitch matching, (2) tinnitus loudness matching and (3) determining tinnitus maskability and residual inhibition. Before pitch matching, participants were asked to indicate whether their tinnitus was tonal or noise-like. Depending on these characteristics, tinnitus pitch matching was performed using pure tone, narrow band noise or white noise. The stimulus was presented in one ear at an intensity of 10 dB SL (Henry, Zaugg, et al., 2005; Vernon & Meikle, 2003). The pitch matching procedure consisted of a two-alternative forced choice procedure and a test for octave confusion (Henry, Zaugg, et al., 2005; Vernon & Meikle, 2003). Tinnitus was matched to half-octave frequencies between 0.125 and 20.0 kHz.

Tinnitus loudness was measured by presenting the pure tone, narrow band (NBN) or white noise (WN) identified by pitch matching to the ipsilateral ear. First, the hearing threshold at this frequency was determined according to the modified Hughson–Westlake method.

Second, the stimulus intensity was increased by 1-dB steps until the patient reported that the stimulus was as loud as the tinnitus. The loudness match was expressed in dB SL.

Tinnitus maskability was examined using both NBN and WN. NBN was presented binaurally for patients with bilateral tinnitus and monaurally for those with unilateral tinnitus at octave frequencies from 0.25 and 8.0 kHz, including 3.0 and 6.0 kHz (Feldmann, 1971). The noise level was raised by 1 dB increments until the patient reported that the tinnitus had become inaudible. The corresponding sound level was defined as the minimum masking level in dB SL. The average minimum masking level (MML) for NBN over all tested frequencies was calculated. The MML for WN was determined by presenting WN binaurally for patients with bilateral tinnitus and monaurally for those with unilateral tinnitus (Henry, Zaugg, et al., 2005). To determine residual inhibition (RI), WN was presented to both ears for one minute at an intensity 10 dB above the MML for WN (Vernon & Meikle, 2003). Afterwards, the patient had to report whether the tinnitus had changed. Four classes of RI were considered: (1) positive, tinnitus disappeared completely; (2) partially positive, tinnitus reduced in loudness; (3) rebound, tinnitus increased in loudness; and (4) negative, tinnitus was unchanged.

**Loudness discomfort levels.** Loudness discomfort levels (LDLs) were measured using the method of Jastreboff and Hazell (2004). At each half-octave frequency between 0.25 and 8.0 kHz and at the tinnitus pitch match, the stimulus was presented at 65 dB HL and then increased in 5 dB steps. Each ear was tested separately. Patients had to indicate the level at which the stimulus became uncomfortably loud. The average LDL was calculated as the average of the LDL-thresholds at each frequency tested.

**Self-reported questionnaires.** All patients completed a Dutch validated version of the Tinnitus Sample Case History Questionnaire (TSCHQ) (Langguth et al., 2007). This consists of 35 questions on patient background, tinnitus history, modifying influences and related conditions. An item list for this questionnaire was developed to achieve data comparability between studies (Langguth et al., 2007). The full item list consists of 14 essential (level A) and 21 highly desirable (level B) items; however, this study evaluated the essential items only. One level A item considered the presence of pulsatile tinnitus, which was used as an exclusion criterion in this study. It was therefore omitted from the analysis and replaced by

an item concerning the subjective description of tinnitus pitch. A validated Dutch version of the Hyperacusis Questionnaire (HQ) was used to quantify and characterize hyperacusis (Khalifa et al., 2002; Meeus, Spaepen, De Ridder, & Van de Heyning, 2010). This questionnaire consists of 14 items with 4 answer possibilities (no; yes, a little; yes, quite a lot; yes, a lot) to yield a score ranging from 0 to 42. A validated Dutch version of the Tinnitus Handicap Inventory (THI) was used to evaluate the tinnitus-related handicap (Newman et al., 1996). The THI is a 25-item questionnaire with 3 answer possibilities (no; yes; sometimes) that yields scores ranging from 0 to 100. It is one of the most commonly used questionnaires to measure the degree of disability caused by tinnitus and to select patients who need intervention (Newman et al., 1996). It has high reliability and construct validity (Newman et al., 1996; Newman, Sandridge, & Jacobson, 1998).

#### **6.2.2.4 Statistical analysis**

Statistical analysis was performed using IBM SPSS Statistics software version 21.0 (Armonk, New York, USA). Descriptive parameters were established for the variables examined during the audiological evaluation and the questionnaire outcomes. Univariate analyses were performed to evaluate the effect of each variable on the THI. For categorical variables, an independent samples t-test or analysis of variance with post-hoc Scheffé testing was conducted. To examine possible correlations between continuous variables, Pearson correlation coefficients (for normally distributed data) or Spearman correlation coefficients were calculated. Correlation coefficients less than 0.30 were considered weak, those between 0.30 and 0.50 were considered moderate and those greater than 0.50 were considered strong (Cohen, Cohen, West, & Aiken, 2013). Bonferroni correction was applied to the results of the univariate analysis. Therefore, a significance level of 0.0023 was used because there were 22 comparisons. Variables showing a significant association with the THI score were subjected to stepwise multiple regression analysis with the THI score as the dependent variable. Correlation between predictor variables was evaluated by collinearity diagnostics and expressed by the variance inflation factor: values less than five implied no correlations among predictor variables (Menard, 2002).

### 6.2.3 Results

The total study sample comprised 81 adults (53 men and 28 women) aged from 18 to 73 years (mean 47.6 years, standard deviation (SD) 14.36 years). The mean  $PTA_{1,2,4}$  kHz was 22.8 dB HL (SD 18.90, range 3–82 dB HL). Tinnitus was unilateral in 45.6 % of patients (16.0 % in the right ear, 29.6 % in the left ear) and bilateral in 54.4 %. The average tinnitus duration was 4.1 years (SD 6.18, range 1–33 years). The median tinnitus pitch was 4.0 kHz (SD 2.64, range 0.125–11.2 kHz) and the mean value for tinnitus loudness was 6.1 dB SL (SD 4.47, 1–21 dB SL). THI scores were normally distributed, with a mean of 44.2 (SD 24.94, range 4–100).

Table 6.1 provides an overview of the variables examined in the audiological evaluation. Psychoacoustic measurements of tinnitus were performed for all except one patient, in whom it was not possible to measure tinnitus loudness because hearing loss was too pronounced. Additionally, it was not possible to determine a complete masking curve in 14 patients because tinnitus symptoms disappeared when NBN was presented (3 patients) or because tinnitus could not be masked with NBN (11 patients). Likewise, the RI could not be determined in nine patients because it was not possible to determine the MML for WN (1 patient) or to mask the tinnitus with WN (8 patients). Table 6.1 further shows the univariate relationship between the variables examined during the audiological evaluation and the THI score. The average LDL was the only variable to show a significant, albeit weak, correlation ( $r=0.265$ ) with the THI score.



Table 6.1 Univariate analysis of the THI and the variables determined during the audiological evaluation.

Variable	n	Value*	THI score (mean ± SD)	Univariate test	
				Test Statistic	P
PTA <sub>1.0,2.0,4.0 kHz</sub> (dB)	81	22.8±18.90	–	r=0.020	0.863
Pitch (kHz)	81	4.0±2.64	–	r <sub>s</sub> =-0.179	0.109
Loudness (dB SL)	80	6.1±4.47	–	r <sub>s</sub> =0.178	0.113
MML WN (dB SL)	72	18.5±13.77	–	r <sub>s</sub> =-0.008	0.946
MML NBN (dB SL)	67	17.6±13.44	–	r <sub>s</sub> =-0.162	0.191
RI				F=2.391	0.058
-Positive	12	14.8	38.2±22.51	–	–
-Partial positive	29	35.8	36.3±21.09	–	–
-Negative	23	28.4	54.6±27.25	–	–
-Rebound	8	9.9	54.5±27.29	–	–
-Not measurable	9	11.1	44.8±24.02	–	–
LDLs <sub>0.25,5.0,1.0,2.0,3.0,4.0,6.0,8.0 kHz</sub> (dB HL)	81	91.4±14.51	–	<b>r=-0.265</b>	<b>0.017<sup>†</sup></b>

Note. \*Data are presented as a percentage or as the mean ± standard deviation. <sup>†</sup>Significant association,  $p < 0.05$ . THI = Tinnitus Handicap Inventory; PTA = pure tone average; MML WN = minimum masking level for white noise; MML NBN = minimum masking level for narrow band noise; RI = residual inhibition; LDLs = loudness discomfort levels

Table 6.2 provides an overview of the TSCHQ (level A items) and the HQ, together with the univariate relationship of their variables with the THI score. For the TSCHQ, items regarding the subjective experience of tinnitus loudness and tinnitus awareness during the day were not completed by two and three patients, respectively. Four variables significantly correlated with the THI score. A weak correlation was found for the subjective experience of tinnitus loudness ( $r_s=0.270$ ), and moderate and strong correlations were found for tinnitus awareness during the day ( $r_s=0.414$ ) and the HQ score ( $r=0.729$ ), respectively. Furthermore, a difference in the THI score was found for noise intolerance. Post-hoc Scheffé tests showed higher THI scores for patients who always or usually experienced noise intolerance compared with patients who sometimes, rarely or never experienced noise intolerance.

Table 6.2 Univariate analysis of the THI and variables of the TSCHQ (14 items) and the HQ.

Variable	n	Value*	THI score (mean ± SD)	Univariate test	
				Test Statistic	P
Age (years)	81	47.4±14.36	–	r=-0.088	0.434
Gender				t= 0.244	0.808
-Male	53	65.4	44.7±25.63		
-Female	28	34.6	43.3±24.01		
Family history of tinnitus				F=0.655	0.522
-Yes, parents	12	14.8	44.3±29.29		
-Yes, brother/sister	9	11.1	53.1±20.86		
-No	60	74.1	42.9±24.71		
Duration (years)	81	4.1±6.18	–	r <sub>s</sub> =-0.071	0.527
Initial onset				t=-1.465	0.146
-Gradual	35	43.2	36.6±25.82		
-Abrupt	46	56.8	47.7±23.94		
Location				F=0.410	0.840
-Right ear	13	16.0	38.5±23.21		
-Left ear	24	29.6	41.1±25.74		
-Both ears, worse right	8	9.9	50.3±24.18		
-Both ears, worse left	5	6.2	48.0±28.28		
-Both ears, equal	23	28.4	46.0±23.15		
-In the head	8	9.9	49.5±33.07		
Subjective loudness (scale 1-100)	78	54.2±23.25	–	<b>r=0.270</b>	<b>0.017<sup>†</sup></b>
Subjective pitch				F=2.088	0.109
-Very high frequency	12	15.0	42.7±21.48		
-High frequency	32	38.8	47.7±26.61		
-Medium frequency	29	36.2	37.2±23.97		
-Low frequency	8	10.0	59.8±22.31		
Tinnitus awareness during the day (scale 1-100)	79	59.9±29.43	–	<b>r<sub>s</sub>=0.414</b>	<b>&lt;0.001<sup>†</sup></b>
Natural masking of tinnitus by environmental sounds				F=2.107	0.128
- Yes	54	66.7	40.3±23.01		
- No	17	21.0	51.8±23.13		
- No idea	10	12.3	52.8±34.31		

Table 6.2 (continued).

Variable	n	Value*	THI score (mean ± SD)	Univariate test	
				Test Statistic	P
Influence of head and neck movement				t=1.291	0.200
- Yes	18	22.2	50.9±24.14		
- No	63	77.8	42.3±25.03		
Subjective hearing impairment				t=0.456	0.501
- Yes	41	50.6	46.0±26.81		
- No	40	49.4	42.5±23.08		
Wearing hearing aids				t=0.681	0.498
- Yes	5	6.2	51.6±27.47		
- No	76	93.8	43.7±24.89		
Subjective noise tolerance				<b>F=4.946</b>	<b>0.001<sup>†</sup></b>
- Never	7	8.6	26.6±15.90		
- Rarely	11	13.6	36.7±13.86		
- Sometimes	37	45.7	38.8±23.95		
- Usually	10	12.3	61.6±27.32		
- Always	16	19.8	58.8±24.05		
HQ score (scale 0-42)	81	18.5±10.10	–	<b>r=0.729</b>	<b>&lt;0.001<sup>†</sup></b>

Note. \*Data are presented as a percentage or as the mean ± standard deviation. <sup>†</sup>Significant association,  $p < 0.05$ . THI = Tinnitus Handicap Inventory; TSCHQ = Tinnitus Sample Case History Questionnaire; HQ = Hyperacusis Questionnaire.

The five variables (one determined through audiological assessment and four determined using questionnaires) retained a significant relation with the THI-score after correction for multiple comparisons in the univariate analysis ( $\alpha=0.05/22$ ). Therefore, all five variables were entered into a stepwise multiple regression model (Table 6.3). The model was statistically significant ( $F(1,76)=58.029$ ,  $p < 0.001$ ), and accounted for 60% of the variance of the THI score ( $R^2=0.611$ ,  $R^2_{\text{adjusted}}=0.600$ ). Tinnitus awareness during the day ( $\beta=0.29$ ,  $p < 0.001$ ), and especially the HQ score ( $\beta=0.65$ ,  $p < 0.001$ ) significantly predicted the THI score.

Table 6.3 Stepwise multiple regression analysis of the variables that were found to have a significant univariate relationship with the THI score.

Variable	b	SE-b	Beta	P
<b>Significant predictors</b>				
- HQ	1.604	0.184	0.654	<0.001
- Tinnitus awareness during the day	0.246	0.063	0.292	<0.001
<b>Excluded variables</b>				
- Subjective loudness	–	–	-0.010	0.907
- LDLs	–	–	-0.031	0.711
- Subjective noise intolerance	–	–	0.086	0.324
Note that the dependent variable was the THI. $R^2=0.611$ , Adjusted $R^2=0.600$ .				
THI = Tinnitus handicap inventory; SE-b = standard error of coefficient b; HQ = Hyperacusis Questionnaire; LDLs = Loudness Discomfort Levels				

#### 6.2.4 Discussion

Tinnitus patients often mention an impact of tinnitus on their quality of life, with the degree of impact varying from person to person (Møller, 2011c). Several studies have addressed the importance of evaluating the psychoacoustic characteristics of tinnitus along with perceived tinnitus severity. However, most of these studies did not find a relationship between tinnitus characteristics and perceived tinnitus severity (Figueiredo et al., 2010; Granjeiro et al., 2013; Hiller & Goebel, 1999; Karatas & Deniz, 2012; Martines et al., 2010; Meikle et al., 1984). Other factors such as hearing loss, hyperacusis and sociodemographic factors including age have also been proposed to influence tinnitus severity (Hiller & Goebel, 2006; Milerová et al., 2013; Schecklmann et al., 2014; Schlee et al., 2011). The present study determined tinnitus characteristics and evaluated the presence of hearing loss and hyperacusis using current audiological assessment methods and questionnaires (Henry & Meikle, 2000; Snow, 2004). Univariate and multivariate analyses were performed to verify which variables were independently related to tinnitus-related handicap as measured with the THI.

The percentage of tinnitus awareness during the day and the HQ score appeared to have independent, significant effects on the THI score. The HQ score was the strongest contributory factor to the THI score in the multiple regression analysis, thus emphasizing the high relevancy of hyperacusis to tinnitus-related handicap. These findings are in accordance with previous reports that the presence of hyperacusis in tinnitus patients increases the

impact of tinnitus on quality of life (Falkenberg & Wie, 2012; Fioretti et al., 2013; Schecklmann et al., 2014). They are also consistent with both tinnitus and hyperacusis inducing emotional and cognitive reactions (Henry, Dennis, et al., 2005; Khalifa et al., 2002). The THI and the HQ quantify attentional and emotional reactions to symptoms associated with tinnitus and hyperacusis, respectively (Khalifa et al., 2002; Newman et al., 1996). This probably explains the strong association between the THI and HQ scores. In addition to quantifying hyperacusis using the HQ, the present study evaluated abnormal sound tolerance by measuring LDLs. Although the average LDL was significantly related to the THI score in a univariate analysis, it had no unique predictive value for the THI score in the multiple regression analysis. No consistent relationship between LDLs and THI score has been reported (Karatas & Deniz, 2012). As such, results suggest that the LDL can be used to identify abnormal sound tolerance but has no additional value over the HQ score for verifying tinnitus-related handicap.

Tinnitus awareness during the day also had a significant effect on the THI score. Wallhäußer-Franke et al. (2012) found that permanent tinnitus awareness influences the subjective loudness of tinnitus and tinnitus severity. The present study showed a weak univariate correlation between the THI score and the subjective experience of tinnitus loudness. However, no correlation was found when loudness was measured audiometrically. According to previous reports, this suggests that the psychoacoustic measurement of tinnitus loudness is not related to tinnitus-related handicap, but that the perceived handicap might influence the subjective experience of tinnitus loudness (Hoekstra et al., 2014; Kuk, Tyler, Russell, & Jordan, 1990).

Similarly, the present study found that neither (subjective) tinnitus pitch and maskability nor the level of RI contribute to the THI score. Several previous studies also reported that tinnitus pitch, maskability and RI have no predictive value for tinnitus severity (Hiller & Goebel, 1999; Karatas & Deniz, 2012; Unterrainer, Greimel, Leibetseder, & Koller, 2003).

Furthermore, the present study did not identify a relationship between the THI score and sociodemographic variables (age and sex) or tinnitus location, initial onset or duration. Additionally, no relationship was found between the THI score and family history of tinnitus, head and neck movements, hearing loss or hearing aid wearing. Previous research also could

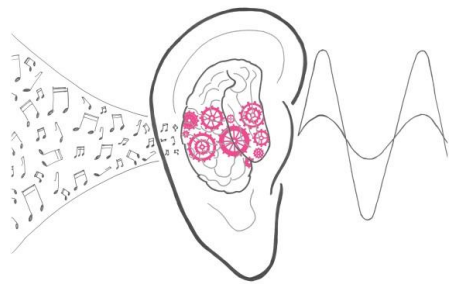
not demonstrate a clear relationship between those variables and tinnitus severity (Andersson et al., 1999; Fioretti et al., 2013, Hiller & Goebel, 1999, 2006; Hoekstra et al., 2014; Karatas & Deniz, 2012; Unterrainer et al., 2003; Wallhäußer-Franke et al., 2012). However, some authors have stated that age and hearing loss have additional influences on tinnitus severity (Hiller & Goebel, 1999, 2006; Schlee et al., 2011; Sindhusake et al., 2004). The THI contains no items on auditory perceptual difficulty (Milerová et al., 2013; Newman et al., 1996). Sensory and perceptual functions decrease with age (Keppler, Dhooge, Corthals, et al., 2010; Patterson, Nimmo-Smith, Weber, & Milroy, 1982). Therefore, the THI might not detect subtle subjective changes associated with ageing and hearing loss. On the other hand, questionnaires containing several items on hearing difficulties might overestimate the score because of the well-known relation between age and reported hearing loss (Milerová et al., 2013).

It should be pointed out that the present study used only the THI to measure tinnitus-related handicap. It is possible that other results would have been found with other questionnaires, such as the Tinnitus Questionnaire or the Tinnitus Handicap Questionnaire (Goebel & Hiller, 1994; Kuk et al., 1990). The lack of a 'gold standard' for measuring tinnitus-related handicap is well known. Moreover, previous research showed that the THI and the Tinnitus Questionnaire measure tinnitus-related handicap in a broadly similar way (Hoekstra et al., 2014; Milerová et al., 2013). Nevertheless, small differences between questionnaires do exist and these should be taken into account when these tools are used to subjectively identify perceived tinnitus-related handicap (Milerová et al., 2013).

### **6.2.5 Conclusion**

Tinnitus awareness during the day, and hyperacusis especially, appear to be related to the THI score. Questionnaires on tinnitus and, especially, on hyperacusis were most suited to providing insight into the impact of tinnitus. Therefore, we recommended including a hyperacusis questionnaire when evaluating tinnitus patients. Furthermore, assessing tinnitus awareness and hyperacusis makes it possible to identify patients at risk of increased tinnitus-related handicap who need more extensive counselling. In addition, this study confirms that the relationship between the audiological characteristics of tinnitus and the perceived tinnitus-related handicap is not straightforward. Nevertheless, a medical and audiological

evaluation of tinnitus is still necessary to explore the underlying medical otological conditions. Finally, this study was cross-sectional and evaluated the characteristics of tinnitus and tinnitus-related handicap during a single consultation. Therefore, further research is needed to examine the long-term effects of factors associated with the impact of tinnitus on quality of life and to determine how these may change over time or might be influenced by counselling or therapy.



## **CHAPTER 7**

### **The evaluation of listening effort in a general and specific population**

## **PART I**

### **The use of a dual-task test to measure listening effort in adults: the effects of age**

Based on:

Degeest S, Keppler H, Corthals P.(2015). The effect of age on listening effort. *Journal of Speech, Language and Hearing Research*, 58(5), 1592-1600.

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**Abstract**

**Purpose.** The objective of this study was to investigate the effect of age on listening effort.

**Method.** A dual-task paradigm was used to evaluate listening effort in different conditions of background noise. Sixty adults ranging in age from 20 to 77 years were included. A primary speech-recognition task and a secondary memory task were performed both separately and simultaneously. Multiple regression analyses were used to evaluate how age and hearing thresholds affect speech-recognition and listening effort scores.

**Results.** Results of the multiple regression analyses showed that age is a significant determinant of listening effort, whereby listening effort increases with increasing age, even when age-related variance in speech-recognition is partialled out. Based on the regression equations and the median score for listening effort, it was found that listening effort started to increase in the fourth decade of life.

**Conclusions.** This study was a first exploration of listening effort from young to older adults and showed that, independent of hearing sensitivity, listening effort increases with age. More specifically, there is a need to further investigate the cognitive functions important for speech-communication while exploring their possible relation with listening effort.

### 7.1.1 Introduction

Older individuals often indicate difficulties with understanding speech in unfavorable listening conditions (Committee on Hearing and Bioacoustics and biomechanics (CHABA), 1988). Moreover, previous research showed that speech performance is significantly poorer for middle-aged adults compared with younger adults in the presence of background noise (Helfer & Vargo, 2009).

It has been hypothesized that the difficulties in understanding speech with increasing age may arise from declines in lower-level sensory and perceptual processes (Baltes & Lindenberger, 1997; Keppler, Dhooge, Corthals, et al., 2010; Lindenberger & Baltes, 1994; Pichora-Fuller & Singh, 2006; Schneider et al., 2002). Indeed, loss of hearing sensitivity in the high-frequency region, which results in a loss of phonemic information and word identification, is mostly evident from the age of 60 years (Gates & Mills, 2005; Van Rooij & Plomp, 1992). However, difficulties with speech understanding in adverse listening conditions is found in older adults (Desjardins & Doherty, 2013; Wingfield, McCoy, Pelle, Tun, & Cox, 2006) as well as middle-aged adults with clinically normal peripheral hearing sensitivity (Helfer & Vargo, 2009; Morrell, Gordon Salant, Pearson, Brant, & Fozard, 1996). Therefore, it was suggested that factors other than peripheral hearing loss additionally contribute to the difficulties in speech understanding experienced by middle-aged and older adults (Desjardins & Doherty, 2013; Helfer & Vargo, 2009). These factors may relate to cognitive functions (Dubno, Dirks, & Morgan, 1984; Schneider et al., 2002) and, more specifically, to working memory, processing speed, and selective attention (Akeroyd, 2008; Pichora-Fuller et al., 1995). These cognitive functions decline with increasing age (Salthouse, 1985, 1996) with evidence from previous research that these declines begin to manifest from middle adulthood (Gunstad et al., 2006; Singh-Manoux et al., 2012).

Consequently, noisier listening situations require more higher-level cognitive resources to compensate for lower-level loss of information (Schneider et al., 2002). When a listener must expend more cognitive resources in order to understand speech in the presence of background noise, the listening task becomes more difficult and effortful. In literature, the cognitive requirements necessary to understand speech have been defined as listening effort (Bourland-Hicks & Tharpe, 2002).

An objective method to assess listening effort in different listening conditions is based on a dual-task paradigm (Bourland-Hicks & Tharpe, 2002; Fraser et al., 2010; Gosselin & Gagne, 2011; Howard et al., 2010; Rabbitt, 1966; Sarampalis et al., 2009). This paradigm, which implies performing a primary task while conducting a concurrent secondary task, exploits the limited capacity of the brain to process information (Akhtar, 2011; Broadbent, 1958; Kahneman, 1973). The primary task uses the required mental capacity while the spare mental capacity is used to complete the secondary task (Kahneman, 1973). Any condition making the primary task more difficult results in less spare mental capacity to perform the secondary task. Therefore, poorer performance on the secondary task indicates more listening effort (Downs, 1982).

The effect of age on listening effort using a dual-task paradigm was investigated by several studies (Desjardins & Doherty, 2013; Gosselin & Gagne, 2011; Larsby, Hällgren, Lyxell, & Arlinger, 2005; Tun, Benichov, & Wingfield, 2008; Tun, McCoy, & Wingfield, 2009). In general, these studies typically investigated the effect of age by comparing younger and older adults and found increased listening effort in the older age group. On the basis of studies that have investigated capacity theory and age-related cognitive and sensory declines (Chisolm, Willott, & Lister, 2003; Kricos, 2006; McCoy et al., 2005; Tun et al., 2008; Wingfield & Tun, 2001, 2007), the present study also included middle-aged adults for whom listening effort has, to the best of our knowledge, not yet been explored extensively.

Furthermore, the capacity theory includes the assumption that when the lower-level perceptual system is taxed more, the capabilities of higher-level cognitive systems are negatively affected (Kahneman, 1973). Hence, it could be expected that listening effort would increase in an unfavorable listening condition compared with a favorable listening condition. In the current study, such listening conditions were used to examine how listening effort might differ in adults with increasing age in a condition in which speech understanding is relatively easy as well as in a condition in which speech understanding is more difficult and thus probably more cognitively demanding. Thus, the goal of the current study was to explore the effects of age on listening effort in different listening conditions using a dual-task paradigm.

## 7.1.2 Methods

### 7.1.2.1 Participants

The study sample consisted of 60 adults ranging from 20 to 77 years of age (mean 47.9 years, SD 17.99 years). None of the participants had a history of communication or learning problems, and none had known neurological disorders. Moreover, adults aged 60 years or older were screened using the Montreal Cognitive Assessment (Nasreddine et al., 2005) in order to exclude various cognitive impairments. Middle-ear function was within normal limits on tympanometry (AA222 Audio Traveller, Interacoustics, Assens, Denmark). Hearing status was evaluated using the modified Hughson-Westlake technique at octave frequencies between 0.25 and 8.00 kHz, including half-octave frequencies of 3.0 and 6.0 kHz (AA222 Audio Traveller, Interacoustics). As shown in Figure 7.1, all subjects had normal age-related hearing with hearing thresholds in both ears equal to or better than the 95th percentile value for gender- and age-corrected frequency-specific threshold norms according to ISO 7029 (International Organization for Standardization, 2000). For each participant, the average hearing threshold was calculated as the average of the thresholds at 0.25, 0.5, 1.0, 2.0, 3.0, 4.0, 6.0, and 8.0 kHz. This study was approved by the local ethical committee. All participants agreed with an informed consent in accordance with the statements of the declaration of Helsinki.

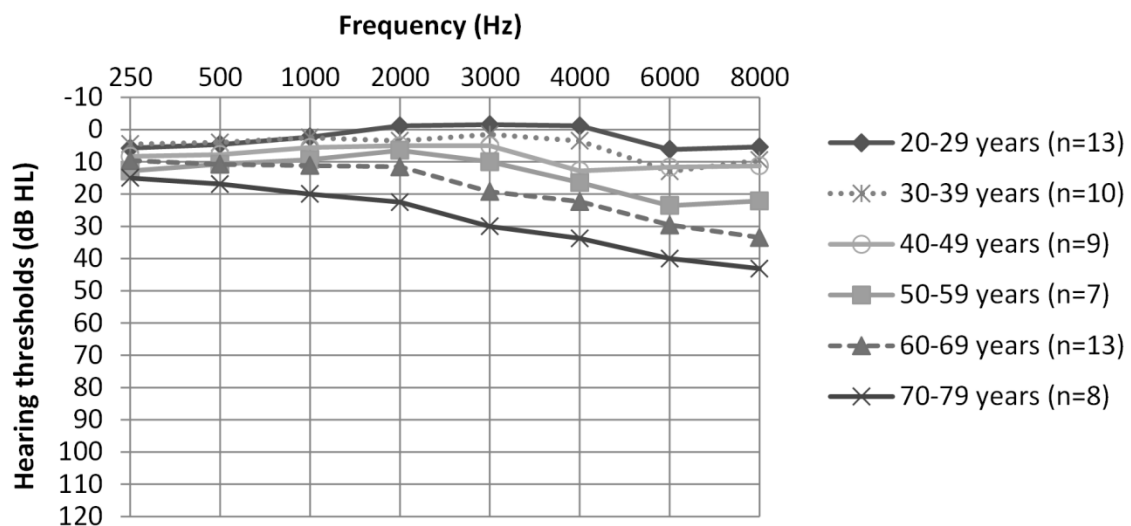


Figure 7.1 Average hearing thresholds of the subjects included in this study, stratified according to ISO 7029:2000.

### 7.1.2.2 Dual-task format

A primary task and a secondary task were performed both separately (further described as the baseline condition) and simultaneously (further described as the dual-task condition). The primary task consisted of a speech-recognition test in different conditions of background noise. The secondary task was a visual memory task. On the basis of previous laboratory pilot work, the design of both the primary speech-recognition task and the secondary memory task was evaluated to control for floor or ceiling effects.

**Primary task.** The primary task was a speech-recognition task. Monosyllabic digits from zero to 12 were used as speech material, whereby the numbers seven and nine were excluded because they are pronounced as two-syllable digits in Dutch. All digits were spoken by a native Flemish female speaker without coarticulation from one digit to another. Series of five digits were used as increasing the number of independent items to be remembered enhances measurement accuracy (Smits et al., 2004; Versfeld, Daalder, Festen, & Houtgast, 2000). The rationale for spoken digits as stimuli was threefold. First, digits are very familiar speech material and can therefore be used in most populations and settings. Second, the test can be repeated without familiarity effects because participants cannot remember which digit combinations were used before (Smits et al., 2004). Finally, when using digits, the participants cannot make use of context to aid comprehension. Recordings were made using the main program on the Computerized Speech Lab (model 4500; Kay Elemetrics Corporation, Lincoln Park, NJ) at a 44.100 Hz sampling rate and digitally stored on a laptop computer. A steady state noise was generated and spectrally shaped in order to reflect the long-term average speech spectrum of the speech material. The digits and the noise masker were normalized to the same root-mean-square pressure level using Adobe Audition CC (Adobe Systems Software, Ireland). Each digit was subsequently digitally mixed with the noise to create different listening conditions with a signal-to-noise ratio (SNR) between +4 and -10 dB. For each spoken digit, the noise masker started 200 ms before onset and ended 200 ms after offset.

The noise-mixed digits were presented through two standard available speakers (Creative Inspire 265, Creative Technology Ltd.). Participants were placed at 45° and 315° azimuth at a distance of 90 cm from each loudspeaker in order to maximize the direct-to-reverberant

ratio (Culling, Zhao, & Stephens, 2005). The equipment was calibrated using a 2250-B Brüel en Kjaer real time sound analyzer (Brüel & Kjær, Denmark) so that the noise level was fixed at 65 dB SPL. For example, in a condition with an SNR of +2 dB, the level of the noise was 65 dB SPL and the level of the digits was 67 dB SPL.

**Secondary task.** The secondary task involved a visual memory assignment in which participants had to keep track of the position of simple geometric figures in a raster on a standard computer screen. These geometric figures were identical blue filled circles, appearing successively for 1 s in the raster (example in Figure 7.2). As in the primary task, series of five assignments were used in order to make suitable demands on cognitive abilities (Smits et al., 2004; Versfeld et al., 2000). The participant was seated on a chair, and the computer screen was placed at eye height, 70 cm in front of the participant. At the beginning of the test, it was asked if the participant could clearly distinguish the geometric figures on the screen. None of the participants indicated difficulties as far as visibility was concerned. Furthermore, it was ensured that all participants had normal or corrected-to-normal visual acuity as measured with Sloan Letters at a distance of 6 m (Sloan, Rowland, & Altman, 1952).

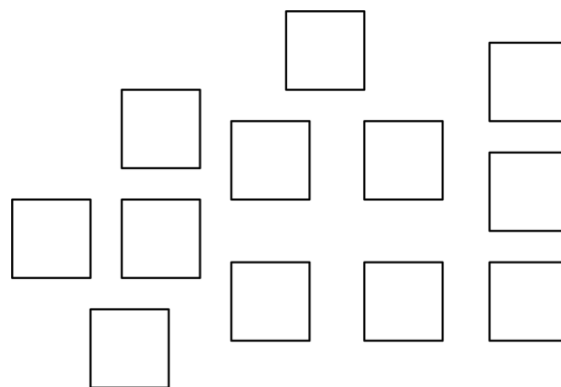


Figure 7.2 Example of the raster in which participants had to keep track of geometric blue filled circles.

### 7.1.2.3 Test procedure

All testing was carried out in a quiet non-reverberant room, illuminated with daylight and standard room lighting. To enable accurate testing, the ambient sound pressure levels at each frequency band between 0.25 kHz and 8.0 kHz were measured using a 2250-B Brüel en Kjaer real time sound analyzer (Brüel & Kjær, Denmark). It was ensured that the ambient

sound pressure levels did not exceed any of the levels specified by the ISO 8253-1 guidelines for accurate testing of normal air conduction hearing threshold levels (International Organization for Standardization, 1989).

**Baseline condition.** Prior to dual-task testing, primary and secondary task baseline test measures were obtained. Each baseline measurement was preceded by a short example of the task to ensure that the participants understood the instructions and were familiar with it. Besides, it was ensured that all participants could fully complete both the baseline primary and secondary task measurements. If one or both tasks could not fully be completed, the person was excluded from the study. Subjects were also excluded if they could not reach a score of 50% correct on the baseline memory task. Baseline conditions were performed at two fixed SNRs, namely a SNR of +2 dB and a SNR of -10 dB, representing a favorable and an unfavorable listening condition. These fixed listening conditions were retained based on previous laboratory work and on literature (Fraser et al., 2010; Gosselin & Gagne, 2011). In addition to these fixed listening conditions, the difficulty of the speech-recognition task was equated to control for age-related variance in baseline speech-recognition performance (Gosselin & Gagne, 2011).

To determine baseline values for the speech-recognition task, two series of five digits were presented at each fixed SNR. The participants were asked to verbally repeat the digits after they were presented all five. Word scoring was used, so that each listening condition was scored out of 10 points. For each participant who did not reach a speech intelligibility of approximately 80% at one of the fixed listening conditions, a level-setting procedure was performed to determine the SNR at which they reached approximately 80% performance (i.e. equated performance condition). Specifically, two series of five digits were presented at SNRs from +4 dB and -10 dB and the multiples of 1 dB within this bracket. Only 5 participants reached already 80% speech performance in one of the fixed listening condition. However, each participant was able to reach 80% speech intelligibility at a SNR between +4 dB and -10 dB during the level-setting procedure. In each condition of the baseline speech-recognition task, the occurrence of each digit across each of the series was randomized, as well as the order of presentation for the different SNRs.



Baseline values for the memory task were determined by presenting five circles successively on the raster. Participants were instructed to memorize the positions within the raster where circles had appeared and to indicate these positions on the score form after each series. For each circle correctly designated, one point was assigned. Five sequences of five circles were presented, but only the score for the 4th and 5th series were used to determine the baseline score in order to control for learning effects and decrease in concentration. In prior pilot work, 18 series of 5 circles were used and showed that the first three series had a lower score because the participants were not yet familiar with the assignment.

**Dual-task condition.** Two sequences of five digits together with five circles appearing on the raster in the dual-task condition were presented at each fixed SNR as well as at the condition where baseline speech performance was equated. As was done during baseline tests, the occurrence of each digit across each series was randomized as well as the order of presentation for the different SNRs. To avoid a conditioning effect, the auditory presentation of a digit and the appearance of a circle were not exactly simultaneous. Also similar to baseline testing procedures, participants were asked to verbally repeat the digits after they were presented all five. Subsequently, they had to indicate on a score form where each of the five circles had appeared in the raster. The verbal instructions were similar to those used in previous experiments that used a dual-task paradigm (Bourland-Hicks & Tharpe, 2002; Gosselin & Gagne, 2011). More specific, under dual-task conditions, participants were instructed as follows: “You have two assignments to complete. You will hear five digits in background noise. Simultaneously, five blue circles will appear in the raster. Please repeat the series of digits after it is presented; this speech-recognition task is the more important of the two tasks. Subsequently, indicate the positions within the raster where circles have appeared as accurately as you can.” The same verbal instructions were used in each of the experimental conditions. Scoring for repeated digits and designated circle positions was done using the same protocol as in the baseline condition.

Listening effort was calculated as the change in visual memory performance from the baseline condition to the dual-task condition in order to control for differences in baseline performance among individual participants (Listening effort =  $100 * (\text{score in baseline condition} - \text{score in dual-task condition}) / \text{score in baseline condition}$ ) (Kemper, Schmalzried, Herman, Leedahl, & Mohankumar, 2009).

#### **7.1.2.4 Statistical analysis**

Statistical analysis was performed using SPSS version 21 (SPSS Inc., Chicago IL). Descriptive parameters were established for the primary and secondary task outcomes in both baseline and dual-task conditions.

Paired Student's t-tests were used to compare the scores of the primary task between baseline and dual-task conditions. Furthermore, a Pearson correlation analysis was used to examine the relationship between a participant's baseline and dual-task secondary task score.

The effect of age on the primary task scores was examined using regression analyses. Because participants were matched for age-related hearing thresholds, the effect of a person's peripheral hearing status on speech performance was taken into account. Therefore, the effect of age and the average hearing threshold on the baseline primary task was evaluated using a stepwise multiple regression analysis. Because two listening conditions (SNR +2 dB and SNR -10 dB) were used in the study, two regression models (Model 1 for speech performance at a SNR of +2 dB and Model 2 for speech performance at an SNR of -10 dB) were constructed to predict speech performance at each SNR. The effect of age on the baseline secondary task scores was evaluated using a Spearman correlation analysis.

The effect of age and the average hearing threshold on listening effort subsequently was examined using a stepwise multiple regression analysis. Two more regression models were constructed to predict listening effort at each SNR (Model 3 for listening effort at an SNR of +2 dB and Model 4 for listening effort at an SNR of -10 dB). Likewise, the effects of age and the average hearing threshold on listening effort were evaluated in the condition in which baseline primary task scores were equated (Model 5). For each model, the correlation between the predictor variables was estimated by collinearity statistics and expressed by the variance inflation factor. Variance inflation factor values below five imply no intercorrelations between the predictor variables (Menard, 2002).

Last, the quartiles of the listening effort scores were calculated for both fixed listening conditions and the equated performance condition in order to explore the possibility of determining a critical age at which listening effort levels may start to rise considerably.

### 7.1.3 Results

#### 7.1.3.1 Baseline Task Performance

The effect of age and hearing thresholds on the primary task scores (i.e., the speech-recognition scores) in the listening condition with an SNR of +2 dB (Model 1) and the listening condition with an SNR of -10 dB (Model 2) was evaluated using a stepwise multiple regression analysis (Table 7.1). In both models, only age significantly predicted speech-recognition scores, whereby scores were lower with increasing age.

In addition to the fixed listening conditions, the baseline speech-recognition task was equated (approximately 80%) in order to control for the confounding influence of differences in speech-recognition scores. The SNR yielding 80% performance ranged from +4 to -10 dB with a median of -6 dB. No significant correlation was found between age and equated speech-recognition scores ( $r_s = -0.215$ ;  $p > 0.05$ ). This result indicated that performance for the baseline speech-recognition ability was successfully equated.

The secondary task consisted of a visual memory task. The mean percentage score on the baseline secondary task was 95.2% (SD 7.48, range 70–100%). No significant correlation was found between age and score on the baseline visual memory task ( $p > 0.05$ ).

Table 7.1 Results of the multiple regression analyses testing the effect of age and the average hearing threshold on speech performance at a SNR of +2 dB (Model 1) and a SNR of -10 dB (Model 2).

Variable	b	SE-b	Beta	t	p	F	R <sup>2</sup>	R <sup>2</sup> adjusted
<b>Model 1: speech performance at SNR +2dB</b>	–	–	–	–	<0.001	16.35	0.22	0.21
<b>Significant predictors</b>								
-Constant	107.99	4.13	–	26.13	<0.001	–	–	–
-Age	-0.33	0.08	-0.47	-4.04	<0.001	–	–	–
<b>Excluded variables</b>								
-Hearing thresholds	–	–	-0.12	-1.06	0.300	–	–	–

Table 7.1 (continued).

Variable	b	SE-b	Beta	t	p	F	R <sup>2</sup>	R <sup>2</sup> adjusted
<b>Model 2: speech performance at SNR -10dB</b>	–	–	–	–	<0.001	54.63	0.49	0.48
<b>Significant predictors</b>								
-Constant	88.02	5.08	–	17.33	<0.001	–	–	–
-Age	-0.73	0.10	-0.70	-7.39	<0.001	–	–	–
<b>Excluded variables</b>								
-Hearing thresholds	–	–	-0.25	-1.70	0.095	–	–	–

Note. For each model, F-values, R<sup>2</sup> and R<sup>2</sup><sub>adjusted</sub> are presented. The 'R<sup>2</sup>' denotes how much of the variability in the outcome is explained by the model. R<sub>adjusted</sub><sup>2</sup> denotes the adjusted proportion of the variance explained by the model. For each predictor in the model, unstandardized and standardized beta-values as well as significance levels are presented.

### 7.1.3.2 Dual-Task Performance

Paired Student's t-tests were performed to evaluate the assumption that a participant's performance on the primary task (i.e., the speech recognition task) remained stable between baseline and dual-task conditions (Kahneman, 1973). At the SNR of +2 dB, speech-recognition scores did not differ significantly between baseline condition (M=92.3%, SD=12.54) and dual-task condition (M=92.7%, SD=9.89),  $t(59)=0.24$ ,  $p>0.05$ . Likewise, in the condition with an SNR of -10 dB, speech-recognition scores in the baseline condition (M=53.8%, SD=19.75) and dual-task condition (M=52.8%, SD=18.96) were not significantly different,  $t(59)=0.65$ ,  $p>0.05$ . For the equated performance condition, speech-recognition scores in baseline condition (M=79.8%, SD=5.96) and dual-task condition (M=77.7%, SD=12.67) were also not significantly different,  $t(59)=-1.39$ ,  $p>0.05$ . Subsequently, the correlation between a participant's score on the secondary visual memory task in the baseline and dual-task conditions was calculated. A significant moderate correlation was found for both the listening condition with a SNR of +2 dB ( $r=0.453$ ;  $p<0.001$ ) and a SNR of -10 dB ( $r=0.454$ ;  $p<0.001$ ). Thus, when a participant had a higher score on the baseline memory task, a higher score on the memory task in the dual-task condition was found.

Listening effort was calculated as the change in visual memory performance from the baseline condition to the dual-task condition in order to control for differences in baseline score for the visual memory task. To explore if age and the average hearing threshold could

predict listening effort in the listening condition with a SNR of +2 dB (Model 3) and the listening condition with a SNR of -10 dB (Model 4), a stepwise multiple regression analysis was used (Table 7.2). In both models, only age significantly predicted listening effort, whereby listening effort increased with increasing age (Figures 7.3a and 7.3b). Similar to the processing of the fixed listening conditions, a stepwise multiple regression analysis was used to explore if age and the average hearing threshold could predict listening effort when baseline speech-recognition was equated (Model 5 in Table 7.2) and showed that only age significantly predicted listening effort (Figure 7.3c).

Table 7.2 Results of the multiple regression analyses testing the effect of age and the average hearing threshold on listening effort scores (%) at a SNR of +2 dB (Model 3), a SNR of -10 dB (Model 4) and in a condition where speech performance is equated (Model 5).

Variable	b	SE-b	Beta	t	p	F	R <sup>2</sup>	R <sup>2</sup> adjusted
<b>Model 3: listening effort at SNR +2dB</b>	–	–	–	–	<0.001	37.25	0.39	0.38
<b>Significant predictors</b>								
-Constant	-6.55	3.98	–	-1.65	0.105	–	–	–
-Age	0.47	0.08	0.63	6.10	<0.001	–	–	–
<b>Excluded variables</b>								
-Hearing thresholds	–	–	0.13	0.80	0.428	–	–	–
<b>Model 4: listening effort at SNR -10dB</b>	–	–	–	–	<0.001	53.92	0.48	0.47
<b>Significant predictors</b>								
-Constant	-5.59	4.99	–	-1.12	0.267	–	–	–
-Age	0.72	0.10	0.69	7.34	<0.001	–	–	–
<b>Excluded variables</b>								
-Hearing thresholds	–	–	-0.01	-0.06	0.954	–	–	–
<b>Model 5: listening effort at equated speech performance</b>	–	–	–	–	<0.001	49.76	0.46	0.45
<b>Significant predictors</b>								
-Constant	-4.53	4.57	–	-0.99	0.325	–	–	–
-Age	0.63	0.09	0.68	7.05	<0.001	–	–	–
<b>Excluded variables</b>								
-Hearing thresholds	–	–	-0.04	-0.25	0.802	–	–	–

Note. For each model, F-values, R<sup>2</sup> and R<sup>2</sup><sub>adjusted</sub> are presented. The 'R<sup>2</sup>' denotes how much of the variability in the outcome is explained by the model. R<sup>2</sup><sub>adjusted</sub> denotes the adjusted proportion of the variance explained by the model. For each predictor in the model, unstandardized and standardized beta-values as well as significance levels are presented.

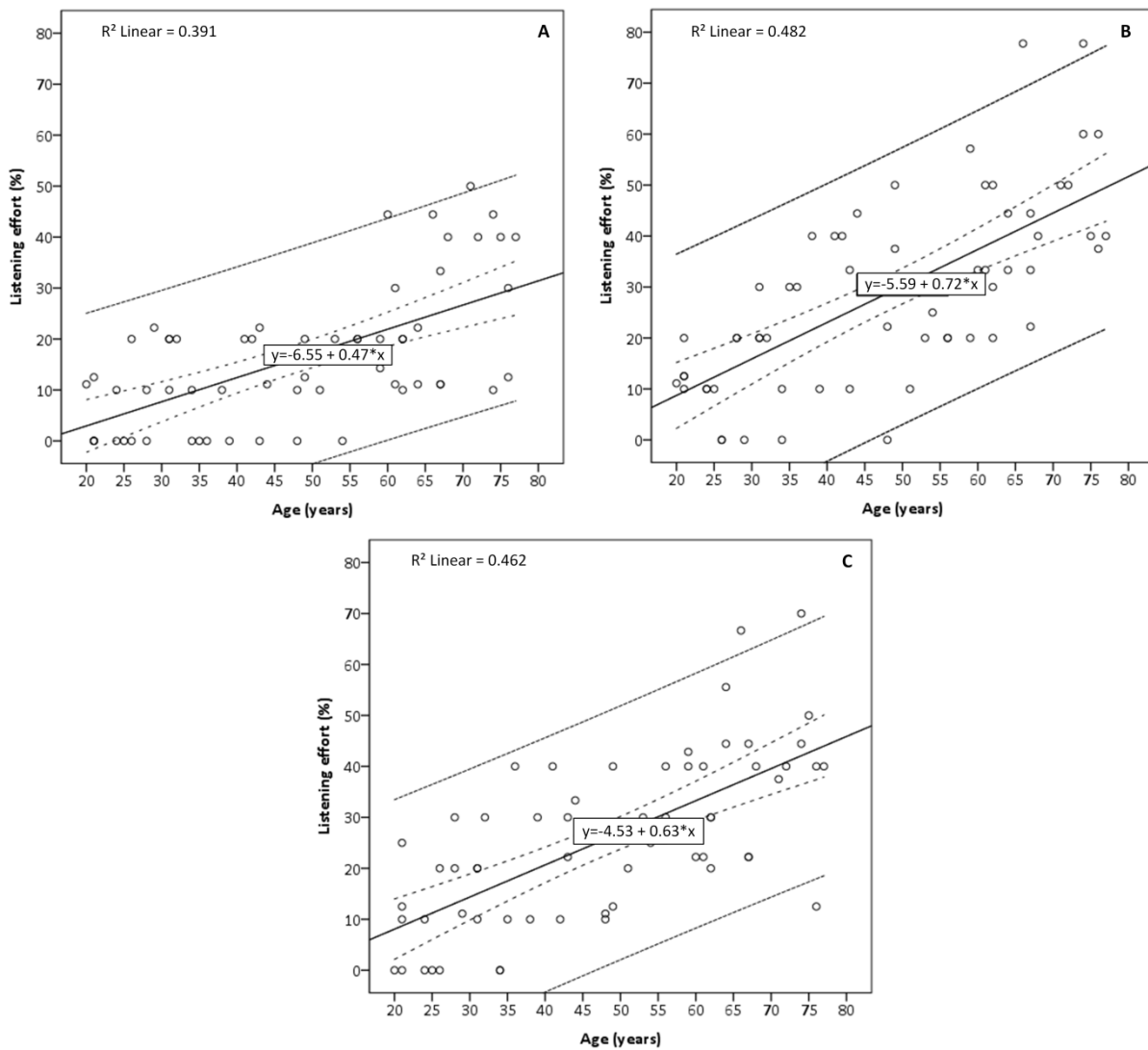


Figure 7.3 Linear regression of the listening effort scores (%) versus age. Solid line indicates linear regression line, dotted lines the 95% confidence limits of linear regression, and dashed lines the prediction intervals. (a) The listening condition with SNR +2 dB, (b) with SNR -10 dB, and (c) at a listening condition in which speech performance is equated.

Because the regression analyses showed that age significantly predicted listening effort in both the fixed listening conditions and in the equated performance condition, it was examined if it was possible to determine a critical age at which listening effort may change. Therefore, the quartiles of the listening effort scores were calculated for both fixed listening conditions and the equated performance condition (Table 7.3). As can be derived from the table, effort levels did not change between the first two quartiles across conditions. However, this difference in effort levels was considerably more between the second and third quartiles. Therefore, the median score (i.e., second quartile) was used as the point at which effort starts to increase notably. By using the median score as y-value in the

regression equation, the corresponding age could be calculated. It was found that for an SNR of +2 dB, listening effort levels start to change notably at the age of 40.5 years. In the case of a listening condition with an SNR of –10 dB, this critical age is 44.1 years. When the equation with equated baseline speech recognition scores is used, the ages at which listening effort changes notably is 44.7 years.

Table 7.3 For the fixed listening conditions (SNR of +2 dB and SNR of -10 dB) and the condition where speech performance is equated, the minimum, maximum and quartile listening effort scores (%) are reflected.

Condition	Minimum	Quartiles			Maximum
		Q1	Q2 (median)	Q3	
SNR +2 dB	0.00	10.00	12.50	20.00	50.00
SNR -10 dB	0.00	12.50	27.50	40.00	77.78
Equated speech performance	0.00	11.11	23.61	40.00	70.00

#### 7.1.4 Discussion

Older individuals often complain of difficulties in understanding speech in adverse listening conditions (Committee on Hearing and Bioacoustics and biomechanics (CHABA), 1988). Also middle-aged adults often indicate that speech intelligibility is very strenuous, especially under less favorable conditions. In general, when an incoming speech signal is distorted, more higher-level cognitive resources will be needed to control for lower-level loss of information, which makes speech understanding more difficult and effortful (Schneider et al., 2002). The present study evaluated the effect of age on listening effort at two fixed SNRs—that is, an SNR of +2 dB and an SNR of –10 dB, representing favorable and unfavorable listening conditions as well as in a condition in which speech performance was equated.

The results of the present study revealed a decline in speech perception associated with aging in both the favorable and unfavorable listening conditions. In general, several studies suggested that the poorer speech performance with increasing age may arise from declines in lower-level sensory and perceptual processes (Baltes & Lindenberger, 1997; Committee on Hearing and Bioacoustics and biomechanics (CHABA), 1988; Dubno et al., 1984; Keppler, Dhooge, Corthals, et al., 2010; Lindenberger & Baltes, 1994; Pichora-Fuller & Singh, 2006;

Schneider et al., 2002). In the present study, hearing thresholds were compared with gender- and age-related thresholds according to the ISO 7029 (International Organization for Standardization, 2000). As a result, hearing thresholds at 4 kHz and beyond could be lower with increasing age due to age-related declines in peripheral functions. Therefore, in addition to age, the predictive effect of a person's average hearing threshold on speech performance was evaluated. Although hearing thresholds were univariately related to speech performance, results of the multiple regression analysis showed no unique significant effect of hearing sensitivity on speech performance. Multiple regression analyses take interdependencies between different variables into account. Because it is well known that hearing sensitivity decreases with age, variables that have been found in studies only performing univariate analyses could be biased due to confounding effects.

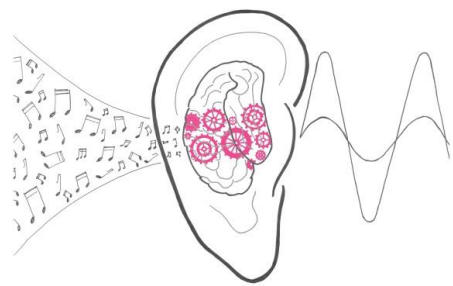
Listening effort was calculated as the change in a participant's performance on the secondary task from the baseline to the dual-task condition while performance on the primary task remained constant. For both fixed listening conditions, age significantly predicted listening effort, whereby listening effort increased with increasing age. Moreover, the predictive value of age on listening effort was very similar in both the favorable and unfavorable listening conditions, which confirmed that listening effort increased in listening conditions in which speech understanding is more difficult. The results of this study are in agreement with the study of Gosselin and Gagne (2011), in which older adults expended more listening effort than younger adults at a fixed SNR. However, the present study also included middle-aged adults and found that listening effort progressively increased with increasing age. One possible explanation for this age–effort relationship could be that the differences in listening effort were due to the age-related differences in speech-recognition scores. The present study therefore evaluated listening effort at SNRs yielding equivalent speech intelligibility scores in order to control for age-related variance in baseline speech-recognition performance. In this condition, a significant difference in listening effort was also found, whereby listening effort increased with age. According to the results for the speech-recognition task, multiple regression analyses revealed that a participant's hearing sensitivity did not predict listening effort in all listening conditions.

Therefore, it appears that factors other than hearing sensitivity have contributed to the age-related increase in listening effort that was found in this study. As assumed by previous



studies, listening effort might be related to a person's cognitive ability. To be more specific, three aspects of cognitive functioning have been reported to be important for speech recognition in noise, namely working memory, processing speed, and selective attention (Akeroyd, 2008; Pichora-Fuller et al., 1995). It has been proven that these functions decline with increasing age (Gunstad et al., 2006; Kemper et al., 2009; Salthouse, 1985, 1996; Singh-Manoux et al., 2012). Moreover, Singh-Manoux et al. (2012) found that these cognitive declines begin at the age of 45 years. If age-related changes in cognitive functioning are related to listening effort, this might explain the finding of the present study that listening effort started to increase in the fourth decade of life in each listening condition. The study by Desjardins and Doherty (2013) evaluated working memory capacity, processing speed, and selective attention in younger and older participants and found reduced abilities for all three cognitive aspects in the older participants compared with the younger participants. Moreover, they found that listening effort was significantly associated with a participant's working memory and processing speed performance. However, the current study did not include standardized tests for cognitive functions and only screened the older participants for normal cognition through the Montreal Cognitive Assessment. Further research, including standardized tests for working memory, processing speed, and selective attention is needed to explore how these cognitive functions contribute to a person's listening effort score, especially in middle-aged adults.

Notwithstanding, this study was a first exploration of listening effort from young to older adults and showed that, independent of hearing sensitivity, listening effort gradually increases with age. The cognitive functions important for speech communication and their possible relationship with listening effort are subjects of further study. The results of the present study also highlight the usefulness of including a test for listening effort in clinical practice to better understand the complaints about speech recognition in noise indicated by middle-aged and older adults.



## CHAPTER 7

### The evaluation of listening effort in a general and specific population

## PART II

### The effect of noise-induced tinnitus on listening effort

Based on:

Degeest S, Keppler H, Corthals P. (2016). The effect of tinnitus on listening effort in normal-hearing young adults: a preliminary study. *Journal of Speech, Language and Hearing Research*, accepted for publication September 12, 2016.

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**Abstract**

**Purpose.** The objective of this study was to investigate the effect of chronic tinnitus on listening effort.

**Method.** Thirteen normal-hearing young adults with chronic tinnitus were matched with a control group for age, gender, hearing thresholds and educational level. A dual-task paradigm was used to evaluate listening effort in different listening conditions. A primary speech-recognition task and a secondary memory task were performed both separately and simultaneously. Furthermore, subjective listening effort was questioned for various listening situations. The Tinnitus Handicap Inventory was used to investigate the contribution of tinnitus handicap to the amount of listening effort.

**Results.** Listening effort significantly increased in the tinnitus group across listening conditions. There was no significant difference in listening effort between listening conditions, nor was there an interaction between groups and listening conditions. Subjective listening effort did not significantly differ between both groups.

**Conclusions.** This study is a first exploration of listening effort in normal-hearing subjects with chronic tinnitus showing that listening effort is increased as compared to a control group. There is a need to further investigate the cognitive functions important for speech understanding and their possible relation with the presence of tinnitus and listening effort.

### 7.2.1 Introduction

Tinnitus can be defined as the perception of sound in the absence of an external physical source (Møller, 2011c). Tinnitus occurs in adults with an overall prevalence of 10 to 15% (Shargorodsky, Curhan, & Farwell, 2010; Sindhusake, Mitchell, et al., 2003) and a wide range of underlying mechanisms or possible origins. For many years, several studies have indicated that excessive noise exposure represents one of the most common causes of tinnitus (Kowalska & Sułkowski, 2001; Penner & Bilger, 1995). Noise-induced tinnitus (NIT) can be acute or chronic. Acute tinnitus can last from a few minutes to a few weeks after noise exposure, whereas chronic tinnitus lasts for months to years (Kaltenbach & Manz, 2011). In addition to the well-known harmful effects of occupational noise, a correlation between leisure noise and tinnitus has already been reported (Davis et al., 1998; Figueiredo et al., 2011). Especially in young adults, there is an increased concern about the effects of leisure noise on hearing, with previous research showing that the prevalence of chronic tinnitus was approximately 6.5% in young Flemish adults exposed to leisure noise (Degeest et al., 2014; Degeest, Keppler, et al., 2016).

Chronic tinnitus can result in comorbid distressing symptoms. A survey by Tyler and Baker (1983), who identified the wide range of effects of tinnitus on quality of life, showed that the most commonly reported problems were related to sleep, impaired speech understanding, depression, impaired concentration, and annoyance. Since several other studies showed similar results, problems faced by tinnitus subjects were grouped into four broad categories (Tyler et al., 2006). The first three categories are related to a person's emotional well-being, hearing and sleep. A fourth category includes concentration difficulties that are often reported by chronic tinnitus patients (Tyler & Baker, 1983), a complaint which has not yet been investigated thoroughly. Problems with concentration are among other factors related to speech understanding in various listening conditions (Andersson et al., 2002; Tyler & Baker, 1983). It has been described that tinnitus can interfere with hearing, for example patients their conversation partner need to surpass the noise of their tinnitus (Tyler et al., 2006). Although hearing loss plays an important role in understanding speech, many patients in clinical practice report that their tinnitus makes speech understanding more difficult than their hearing loss does (Andersson, 2009). The study of Newman, Wharton, Shivapuja, and Jacobson (1994) demonstrated that persons with tinnitus perform worse on difficult speech

understanding tasks compared to persons without tinnitus with similar hearing thresholds. These difficulties were attributed to distraction and irritability caused by the presence of tinnitus, making it difficult to concentrate (Tyler & Baker, 1983). Evidence for this assumption may be derived from research on cognitive functions, which may be deteriorated by the presence of tinnitus (Gatehouse, 1991; Jacobson et al., 1996). Specifically, cognitive functions may be affected because attention is diverted to the tinnitus symptom (Hallam et al., 2004; Hallam, Rachman, & Hinchcliff, 1984), which makes demands on cognitive resources as attention is being divided over several tasks (Stevens, Walker, Boyer, & Gallagher, 2007). Furthermore, tinnitus may disrupt the processing of auditory verbal information that is mediated by working memory (Andersson & McKenna, 2006; Baddeley, 1986). Since attention as well as working memory are reported to be related to speech processing (Pichora-Fuller et al., 1995; Schneider et al., 2002), speech intelligibility may become more effortful for persons with tinnitus because their cognitive reserve is reduced by these side effects of tinnitus (Stevens et al., 2007).

In the literature, cognitive requirements necessary to understand speech have been defined as listening effort (Bourland-Hicks & Tharpe, 2002). An objective method to assess listening effort is based on a dual-task paradigm (Bourland-Hicks & Tharpe, 2002; Fraser et al., 2010; Gosselin & Gagne, 2011; Howard et al., 2010; Rabbitt, 1966; Sarampalis et al., 2009). This paradigm exploits the limited capacity of the brain to process information by asking participants to perform a primary task while conducting a concurrent secondary task (Broadbent, 1958; Kahneman, 1973). Performance on the primary task utilizes the required mental capacity, while performance on the secondary task utilizes the spare mental capacity (Kahneman, 1973). Any condition making the primary task more difficult results in less spare mental capacity to perform the secondary task. Therefore, decreased performance on the secondary task indicates more listening effort (Downs, 1982). Based on the capacity theory (Kahneman, 1973) and literature concerning tinnitus and cognitive performance, it was hypothesized that persons with tinnitus will have to spend more listening effort than persons without tinnitus. The rationale is that cognitive capacities, needed for speech processing, may be taxed more by the presence of tinnitus, leaving less spare mental capacity to perform on a secondary task.

Cognitive impairment in persons with tinnitus was suggested to be influenced by increased levels of tinnitus distress (Rossiter, Stevens, & Walker, 2006; Stevens et al., 2007). In general, high levels of anxiety and emotional distress related to tinnitus may disrupt cognitive performance. On the other hand, there might be an association between tinnitus distress and inappropriate allocation of finite attentional resources in an attempt to monitor tinnitus sensations (Jackson, Coyne, & Clough, 2014). However, the specific effect of tinnitus distress on cognitive performance is still unclear, as some studies found significant relations between distress and response times to cognitive tasks (Jackson et al., 2014; Stevens et al., 2007), while others could not find such results (Dornhoffer, Danner, Mennemeier, Blake, & Garcia-Rill, 2006). Because of the involvement of cognitive capacities in the amount of listening effort and since it is well known that tinnitus is often accompanied by different levels of distress (Degeest, Corthals, Dhooge, & Keppler, 2016), it will be important to control for tinnitus distress as a possible factor that may influence the amount of listening effort. However, in previous research, information on the levels of distress is often missing.

In conclusion, some cognitive functions important for speech processing may be affected by the presence of tinnitus. Hence, based on the capacity theory (Kahneman, 1973), the question was raised if listening effort may be increased in tinnitus patients when performing several tasks simultaneously. It could be expected that listening effort is increased in subjects with chronic tinnitus compared to subjects without tinnitus because the capabilities of the higher-level cognitive systems are taxed more by the presence of tinnitus. Thus, the general goal of this study was to investigate the effect of chronic tinnitus on listening effort. To the best of our knowledge, no research exists pertaining to the effects of tinnitus on listening effort. A more specific purpose of this study was therefore to assess the performances on a dual-task test in normal-hearing young adults with chronic tinnitus -that had existed for at least three months- and a control group without tinnitus matched for gender, age, hearing thresholds and educational level. Results of this study may provide more insight into the concentration difficulties related to speech understanding indicated by persons with tinnitus.

## 7.2.2 Method

### 7.2.2.1 Participants

**Tinnitus group.** The tinnitus group (TG) consisted of 13 adults (7 males and 6 females) aged 19 to 31 years (mean 23.8 years, SD 4.30 years). All participants were native speakers of Dutch. They all experienced chronic tinnitus, which was defined as tinnitus that has occurred for at least 3 months (The National Institute on Deafness and Other Communication Disorders, 1994-1995). One participant (7.7%) experienced tinnitus less than 6 months, 3 participants (23.1%) experienced tinnitus between 6 months and 1 year and 9 participants (69.2%) experienced tinnitus for more than one year. Tinnitus was constant in all participants and referred to as bilateral in 76.9% of the participants and as unilateral in 23.1% of the participants (15.3% right ear and 7.8% left ear). In the majority of the cases (47.8%), tinnitus was described as a pure tone; alternatively it was described as noise (34.8%) or a combination of a pure tone and noise (17.4%). Based on medical history, tinnitus was most probably caused by noise exposure in all participants, whereby noise exposure was related to leisure activities (e.g. music venues or nightclubs and listening to personal music players). None of the participants received any kind of treatment regarding their tinnitus.

For all participants, middle-ear function was within normal limits according to tympanometry results (AA222 audio traveler, Interacoustics, Assens, Denmark). Hearing status was further evaluated using the modified Hughson-Westlake technique at octave-frequencies between 0.25 kHz and 8.0 kHz, as well as at half-octave frequencies 3.0 kHz and 6.0 kHz (AA222 audio traveler, Interacoustics, Assens, Denmark). Hearing thresholds were better than 20 dB HL at each frequency tested. Figure 7.4a shows the mean hearing thresholds for both ears of the tinnitus group.

Furthermore, a validated Dutch version of the Tinnitus Handicap Inventory (THI) (Newman et al., 1996) was used to evaluate tinnitus-related handicap. In order to exclude a possible influence of tinnitus handicap on the amount of listening effort, the score on the THI for each participant had to be lower than 36, which indicates no or minimal impact of tinnitus. The THI is a 25-item questionnaire with three answer possibilities (no; yes; sometimes) yielding total scores ranging from 0 to 100. It is one of the most commonly used



questionnaires to measure the degree of disability caused by tinnitus and to select patients in need of intervention. It has high reliability and construct validity (Newman et al., 1996; Newman et al., 1998). The THI score was 12.2 on average (SD 6.80; range 4 – 30), indicating that all tinnitus subjects experienced no or minimal impact of the tinnitus.

None of the participants had a history of communication or learning problems or any other known neurological disorder that could influence the findings of the current study.

**Control group.** The control group (CG), also consisting of 13 participants, was selected after data collection was completed for the TG. CG participants were also native Dutch speakers. They were each matched to an individual from the TG according to following criteria: (1) age difference was less than two years; (2) individuals were of the same gender; (3) equal educational levels according to UNESCO (2012); (4) hearing thresholds differences were less than 15 dB HL at each tested frequency. The CG consisted of 7 males and 6 females age 20 to 31 years (23.8, SD 3.90 years). Like the TG, none of the participants had a history of communication or learning problems and none had known neurological disorders. An independent samples t-test revealed no significant differences between both groups according to age ( $t(24)=-0.47; p>0.05$ ) and hearing thresholds at each frequency tested ( $p>0.05$ ). Mean hearing thresholds of the control group are shown in Figure 7.4b.

This study was approved by the local Ethical Committee. All participants agreed with an informed consent in accordance with the statements of the declaration of Helsinki.

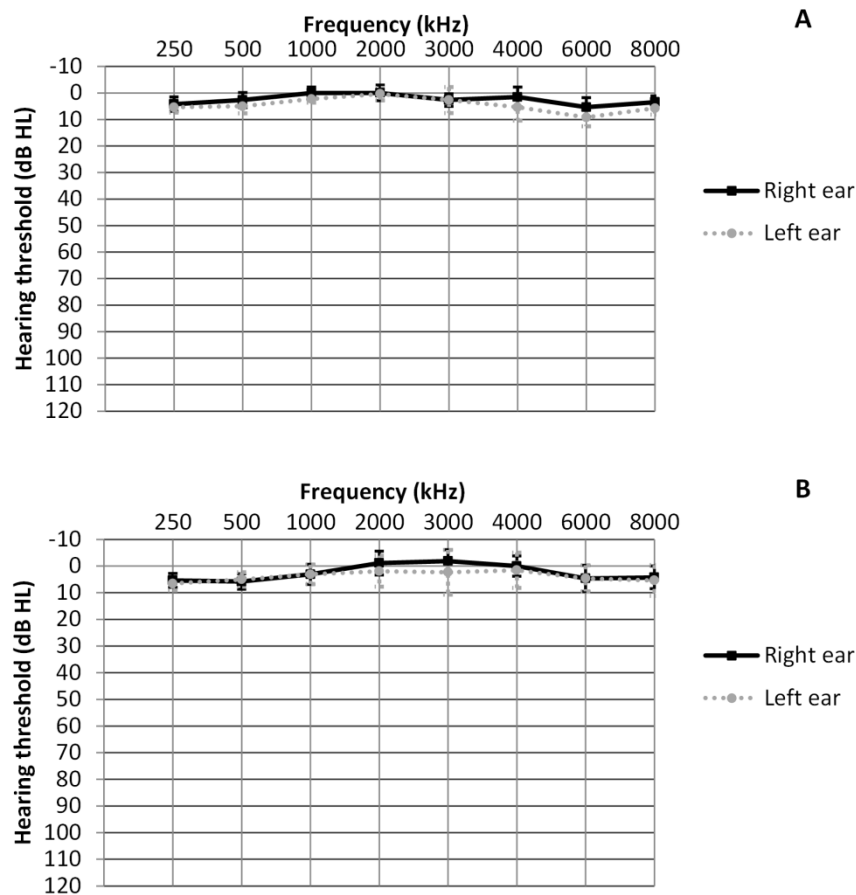


Figure 7.4 Mean hearing thresholds  $\pm$  one standard deviation for the subjects with tinnitus ( $n=13$ , upper part A) and the subjects from the control group ( $n=13$ , lower part B).

### 7.2.2.2 Dual-task format

Listening effort was measured using a dual-task paradigm. A primary task and a secondary task were performed both separately (further on described as the baseline condition) and simultaneously (further on described as the dual-task condition). The primary task consisted of a speech-recognition test in various listening conditions. The secondary task was a visual memory task. A more detailed description of the dual-task format can be found elsewhere (Degeest, Keppler, & Corthals, 2015).

**Primary task.** The primary task was a speech-recognition task. Monosyllabic digits from 0 to 12 were used as speech material. Each spoken digit was digitally mixed with a steady state noise that was spectrally shaped in order to reflect the Long Term Average Speech Spectrum of the speech signals. The sound pressure level of the digits was varied to create different signal-to-noise ratios (SNRs), namely +2 dB and -10 dB, representing a

favorable and an unfavorable listening condition, respectively. In addition, a third listening condition without background noise was used (i.e. quiet condition).

The mix of noise and digits was presented through two standard available loudspeakers (Creative Inspire 265, Creative technology Ltd.). Participants were sitting at 45 and 315 degrees azimuth and a distance of 90 cm from each loudspeaker in order to maximize the direct-to-reverberant ratio (Culling et al., 2005). The equipment was calibrated using a 2250-B Bruël en Kjaer real time sound analyzer (Brüel & Kjær , Denmark) so that the noise level was fixed at 65 dB SPL. For example, in the listening condition with an SNR of +2 dB, the level of the noise was 65 dB SPL and the level of the digits was 67 dB SPL.

**Secondary task.** The secondary task involved a visual memory assignment in which participants had to keep track of the position of simple geometric figures in a raster on a standard computer screen. These geometric figures were identical blue filled circles, appearing successively for one second in the raster (example in Figure 7.5). The participant was seated on a chair and the computer screen was placed at eye height, 70 cm in front of the participant. Before testing, each participant was asked to indicate whether the geometric figures could clearly be distinguished on the screen. None of the participants indicated difficulties as far as visibility was concerned. In addition, visibility was measured with Sloan Letters at a distance of 6 meters (Sloan et al., 1952) to ensure that all participants had normal or corrected-to-normal visual acuity.

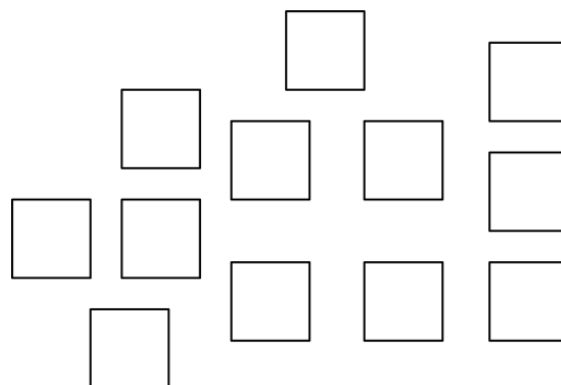


Figure 7.5 Example of the raster in which participants had to keep track of geometric blue filled circles.

### 7.2.2.3 Test procedure

All testing was carried out in a quiet non-reverberant room, illuminated by daylight and standard room lighting. To enable accurate testing, the ambient sound pressure levels at each frequency band between 0.25 kHz and 8.0 kHz were measured using a 2250-B Brüel en Kjaer real time sound analyzer (Brüel & Kjær, Denmark). It was ensured that the ambient sound pressure levels did not exceed any of the levels specified by the ISO 8253-1 guidelines for accurate testing of normal air conduction hearing threshold levels (International Organization for Standardization, 1989).

**Baseline condition.** Prior to dual-task testing, primary and secondary task baseline test measures were obtained. Each baseline measurement was preceded by a short example of the task to ensure that the participants understood the instructions and were familiar with the type of assignment. For both the primary and secondary task, series of five assignments were used in order to make suitable demands on cognitive abilities (Smits et al., 2004; Versfeld et al., 2000). To determine baseline values for the speech-recognition task, two series of five digits were presented at the two fixed SNRs of +2 dB and -10 dB as well as in the quiet condition. The participants were asked to verbally repeat the series of digits after they had been presented all five. Word scoring was used, so that each listening condition was scored out of 10 points. Baseline values for the memory task were determined by successively presenting five circles on the raster. Participants were instructed to memorize the positions within the raster where circles had appeared and to indicate these positions after each series of five on a score form. For each circle located correctly, one point was assigned. Five sequences of five circles were presented, but only the scores for the 4<sup>th</sup> and 5<sup>th</sup> series were used to determine the baseline score in order to control for individual differences in speed of learning.

**Dual-task condition.** In the dual-task condition, two sequences of five digits together with five circles appearing on the raster were presented in each fixed SNR-condition and in the quiet condition. Based on previous experiments that used a dual-task paradigm (Bourland-Hicks & Tharpe, 2002; Gosselin & Gagne, 2011), the verbal instructions used for the dual-task condition were as follows: “You have two assignments to complete. You will hear five digits, either in quiet or in background noise. Simultaneously, five blue circles will

appear in the raster. Please repeat the series of digits after it is presented; this speech-recognition task is the more important of both tasks. Subsequently, indicate as accurately as you can the positions within the raster where circles have appeared.” The same verbal instructions were used in each of the experimental conditions. Scoring for repeated digits and designated circle positions was done using the same protocol as in the baseline condition.

Listening effort was calculated as the change in visual memory performance from the baseline condition to the dual-task condition in order to control for differences in baseline performance among individual participants (Listening effort =  $100 * (\text{score in baseline condition} - \text{score in dual-task condition}) / \text{score in baseline condition}$ ) (Kemper et al., 2009).

For all experimental conditions, the occurrence of digits across each of the series was randomized, as well as the order of presentation of the listening conditions. Furthermore, the auditory presentation of a digit and the appearance of a circle were not exactly simultaneous in order to avoid a conditioning effect.

#### **7.2.2.4 Subjective listening effort**

Subjective effort required for understanding speech in everyday listening situations was questioned in both the TG and the CG for (1) a quiet condition while conversing with one person; (2) a quiet condition while conversing with several persons; (3) a situation with background noise (e.g. restaurant). For each of these conditions, participants had to indicate to what degree they need to make an effort to understand speech by designating one of five answer possibilities (never, rarely, sometimes, often or always).

#### **7.2.2.5 Statistical analysis**

Statistical analysis was performed using SPSS version 21 (SPSS Inc. Chicago IL, USA). Descriptive parameters were established for the primary and secondary task outcomes in both baseline and dual-task conditions as well as for the subjective listening effort outcomes.

Paired Student’s t-tests were used to compare primary task scores between the baseline and dual-task condition. Furthermore, a Mann-Whitney U test was used to compare baseline secondary task scores between the TG and the CG.

A two-way analysis of variance (ANOVA) was conducted to evaluate the influence of two independent variables (group and listening condition) on the primary speech intelligibility scores. The variable group included two levels (tinnitus group and matched-control group) and the variable listening condition consisted of three levels (quiet, SNR +2 dB, SNR -10 dB). Likewise, a two-factor 2x3ANOVA was conducted to evaluate the influence of group and listening condition on listening effort. For both analyses, post-hoc Sheffé testing was performed when the threshold of significance was reached ( $p<0.05$ ). Furthermore, the assumptions for ANOVA were fulfilled (homogeneity of variances, normality).

The effect of the THI score, which was normally distributed, on the degree of listening effort in the TG was evaluated using a Pearson correlation analysis.

Finally, the subjective effort required for speech understanding in different listening conditions was compared between the TG and the CG. Since both the TG and the CG consisted of only 13 participants, the five answer possibilities were reduced to two categories in order to obtain 2x2 contingency tables. Reduction of the answer possibilities was done by combining the 'never' and 'rarely' categories into a single "no effort" category and by combining the 'sometimes', 'often' and 'always' categories into the umbrella category "effort". Subsequently, chi-square tests were used to evaluate the association between subjective effort in the TG and CG. If one or more cells had an expected count less than five, Fisher's exact test was used. For all analyses, a significance level of 0.05 was used.

After all data were collected and analyzed, SAS power and sample size calculator (SAS Institute Inc., North Caroline, USA) was used to evaluate the statistical power of the study sample.

## **7.2.3 Results**

### **7.2.3.1 Baseline Task Performance**

For each listening condition, the average baseline speech-recognition scores for the subjects in the TG and CG are shown in Figure 7.6. The two-factor 2x3ANOVA to evaluate mean differences in speech-recognition scores across groups (tinnitus or control group) and different listening conditions (quiet, SNR +2 and SNR -10 dB) revealed a significant main effect of listening condition on speech-recognition scores ( $F(2,74)=92.62, p<0.05$ ). The group

effect was not significant ( $F(1,74)=0.05$ ,  $p>0.05$ ) and there was also no significant interaction between listening condition and group ( $F(2,72)=1.72$ ,  $p>0.05$ ). Post-hoc Sheffé tests were performed for the variable listening condition, and showed a significant mean difference in speech-recognition scores between the quiet condition and the condition with a SNR of -10 dB, as well as between the condition with a SNR of +2 dB and the condition with a SNR of -10 dB ( $p<0.05$ ).

The mean percentage score on the baseline secondary visual memory task was 98.4% (SD 3.76, range 90 – 100%) for the TG and 99.2% (SD 2.77, range 90 – 100%) for the CG. This difference between both groups was not significant according to the Mann-Whitney U test ( $p>0.05$ ).

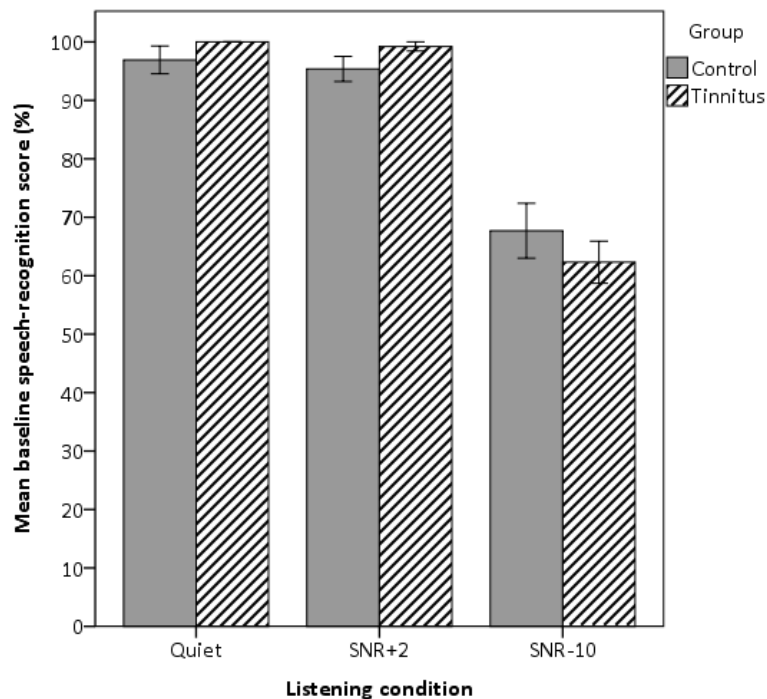


Figure 7.6 Mean speech-recognition score (%) as a function of participant group and listening condition. Error bars refer to standard error of the mean.

### 7.2.3.2 Dual-Task Performance

Paired Student's t-tests were performed to evaluate the assumption that a participant's performance on the primary task (i.e. the speech-recognition task) remained stable between baseline and dual-task conditions (Kahneman, 1973). For the quiet condition, baseline ( $M=98.5\%$ ,  $SD=6.13$ ) and dual-task ( $M=99.6\%$ ,  $SD=1.96$ ) speech-recognition scores were not significantly different ( $t(25)=-1.36$ ,  $p>0.05$ ). Likewise, baseline ( $M=97.3\%$ ,  $SD=6.04$ ) and dual-

task ( $M=98.1\%$ ,  $SD=4.91$ ) speech-recognition scores did not differ significantly at the SNR of +2 dB ( $t(25)= -0.57$ ,  $p>0.05$ ), nor between baseline ( $M=65.0\%$ ,  $SD=15.03$ ) and dual-task ( $M=65.4\%$ ,  $SD=13.34$ ) at the SNR of -10 dB ( $t(25)= -0.15$ ,  $p>0.05$ ).

Subsequently, listening effort was calculated as the change in visual memory performance from the baseline to the dual-task condition. Figure 7.7 shows the average listening effort experienced by subjects in the TG and CG in each listening condition. To compare differences in listening effort across groups (tinnitus or control) and across different listening conditions (quiet, SNR +2 dB and SNR -10 dB), a two-factor 2x3ANOVA was conducted. A significant main effect was found for the variable group ( $F(1,74)=16.69$ ,  $p<0.05$ ), such that participants from the TG ( $M=20.1\%$ ;  $SD=15.52$ ) experienced more listening effort compared to participants from the CG ( $M=8.1\%$ ;  $SD=9.55$ ). The main effect for listening condition was not significant ( $F(2,74)=1.08$ ,  $p>0.05$ ) and also no significant interaction was found between the variables group and listening condition ( $F(2,72)=0.41$ ,  $p>0.05$ ).

The relation between listening effort and the scores on the THI was investigated in the TG using Pearson correlation coefficients. For none of the listening conditions the correlation coefficient fell above 0.3 and none of the correlations was significant ( $p>0.05$ ).

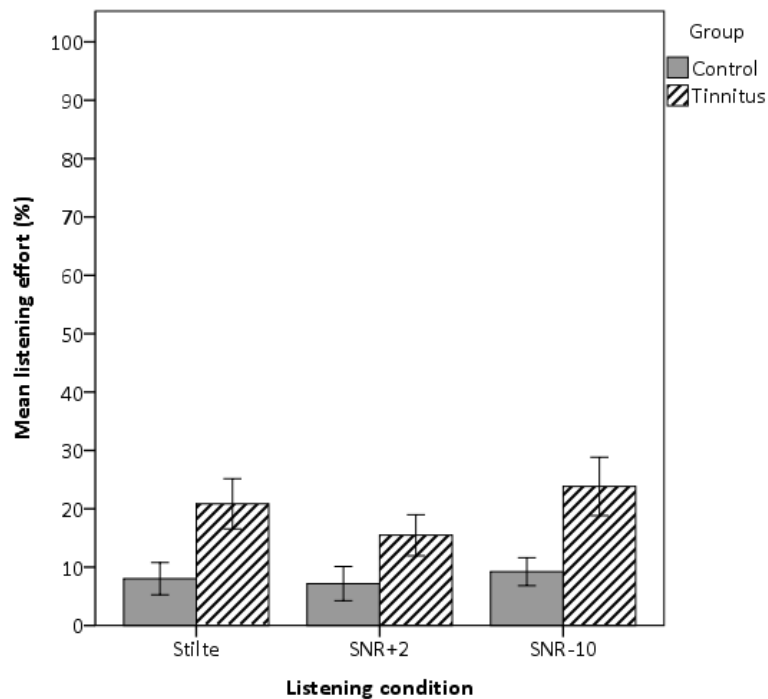


Figure 7.7 Mean listening effort (%) as a function of participant group and listening condition. Error bars refer to standard error of the mean.



### 7.2.3.3 Subjective listening effort

Subjective listening effort was evaluated in both the TG and CG. As shown in Table 7.4, subjects with tinnitus reported having more difficulties with speech understanding in a quiet listening condition while conversing with one person as well as with several persons. However, these differences were not statistically significant ( $p>0.05$ ). For the background noise condition, the differences between both groups became smaller and also not significant ( $p>0.05$ ).

Table 7.4 Subjective difficulties with speech understanding in different listening situations for subjects with tinnitus (n=13) and subjects without tinnitus (n=13).

Difficulties with speech understanding		Group	
		Tinnitus group	Control group
Speech understanding in quiet	% (n)		
- No effort		45.0 (9)	55.0 (11)
- Effort		66.7 (4)	33.3 (2)
Speech understanding in quiet with several persons	% (n)		
- No effort		43.8 (7)	56.2 (9)
- Effort		60.0 (6)	40.0 (4)
Speech understanding in noise	% (n)		
- No effort		37.5 (3)	62.5 (5)
- Effort		55.6 (10)	44.4 (8)

### 7.2.3.4 Power analysis

To evaluate the statistical power of the sample used to detect the effect of tinnitus and listening condition on the amount of listening effort, a power analysis was conducted. Based on the mean listening effort scores of each group in each listening condition, a standard deviation of 12.0 and an alpha value of 0.05, it was found that the effect of tinnitus on the amount of listening effort can be detected with a power of 0.991. In contrast, the effect of listening condition on the amount of listening effort had a power of only 0.263.

## 7.2.4 Discussion

Tinnitus patients complaining of difficulties with concentration related to speech understanding may have to spend more listening effort in various listening conditions (Andersson et al., 2002; Tyler & Baker, 1983). Hence, based on the capacity theory

(Kahneman, 1973), the present study investigated whether listening effort may be increased in tinnitus patients when performing several tasks simultaneously. More specific, the effect of tinnitus on listening effort was assessed in normal-hearing young adults with chronic unilateral or bilateral tinnitus that existed for at least three months.

Listening effort was calculated as the change in a participant's performance on a memory assignment from the baseline to the dual-task condition. The results showed that, across listening conditions, listening effort was significantly higher for the participants with tinnitus compared to the control group. A possible explanation for the differences in listening effort might be that the incoming speech signal was distorted in the tinnitus subjects. Previous research has shown that tinnitus complaints may be related to an underlying dysfunction of the auditory system (Hallam et al., 1984) and that it may interfere with the ability to hear sounds over the tinnitus (Tyler et al., 2006). However, the tinnitus subjects as well as the control subjects in the present study had normal hearing thresholds through 8.0 kHz, which can exclude a clinical relevant distortion of the incoming speech signal due to auditory deteriorations. Moreover, no significant differences in baseline speech perception performance were found between the subjects with tinnitus and the control subjects for all listening conditions. Complaints about tinnitus may also be related to psychological factors (Hallam et al., 1984; Hoekstra et al., 2014). High self-attenders, who tend to give more attention to somatic sensations, are found to be more depressed and more distressed due to tinnitus and have greater perceived tinnitus handicap (Newman, Wharton, & Jacobson, 1997). A cycle of increased negativity and anxiety may develop, which in turn can lead to cognitive impairment (Hallam et al., 1984). Therefore, the present study evaluated tinnitus handicap using the THI. All tinnitus subjects had low THI-scores and also no significant relations were found between the THI-score and listening effort, which indicates that tinnitus handicap did not influence the amount of listening effort.

These findings suggest that factors other than hearing or tinnitus handicap may have contributed to the increased listening effort in the subjects from the tinnitus group. To be more specific, listening effort was considered to be related to cognitive processes required for speech understanding, namely selective attention, working memory and processing speed (Akeroyd, 2008; Pichora-Fuller et al., 1995; Pichora-Fuller & Singh, 2006). Several authors have suggested that especially selective attention (Andersson, Eriksson, Lundh, &

Lyttkens, 2000; Hallam et al., 2004; McKenna & Hallam, 1999) and working memory capacity (Baddeley, 1986; Rossiter et al., 2006; Stevens et al., 2007) could be affected by the presence of tinnitus. In this respect, the most reasonable interpretation of the increased listening effort found in subjects with tinnitus concerns a shift of attention towards the tinnitus, which can be considered as task irrelevant information (Hallam et al., 2004; Hallam et al., 1984). Hence, cognitive capacity may have been reduced in the tinnitus subjects because their attention was divided over more than two tasks (i.e. the dual-task test stimuli and the tinnitus signal), which increased demands on auditory processing. Besides, previous research suggested that tinnitus can interfere with the phonological loop to store auditory verbal information (McKenna, 1997). Dual-task paradigms assume a limited capacity of the brain to process information so that fewer cognitive resources are available when individuals are required to divide their attention between two tasks. Consequently, subjects with tinnitus may have less spare cognitive capacity left to perform on the secondary memory task because a fraction of their cognitive capacity is claimed by the presence of tinnitus, thereby making the listening task more difficult and effortful.

The dual-task paradigm further assumes that when the primary task becomes more difficult, more cognitive resources are directed to that task, leaving fewer resources available to perform the secondary task. The present study, however, found no significant difference in listening effort across the listening conditions, a result that might be related to the performance levels for the primary speech recognition test. For both the TG and CG, speech-recognition scores were not majorly affected with an average of more than 90% in the favorable conditions (i.e. quiet condition and SNR of +2 dB) and more than 60% in the unfavorable condition (i.e. SNR of -10 dB). These differences in speech recognition between both listening conditions suggest that the cognitive load imposed by the speech assignments in each of the conditions did not differ enough to create a substantial contrast in listening effort.

In addition, no significant interaction was found between the groups and listening conditions, which indicates that the impact of tinnitus on listening effort does not depend on the listening condition. However, if attentional resources are taxed more by attending to the tinnitus symptom, one could expect that subjects with tinnitus may have experienced more listening effort in the quiet condition compared to the noise conditions because tinnitus is

probably more prominent when there is no additional background noise to mask it. A possible reason for the lack of interaction between groups and listening conditions pertains to the design of the used dual-task test. First, between the different assignments, there was a short interruption where participants had to indicate their answers from the secondary task on a score form. According to previous research (Banbury & Berry, 1997), habituation to task irrelevant information (in this case the tinnitus symptom) may occur during complex tasks, though a short interruption may cause disruption again. Second, there was a short (1 to 2 seconds) silent gap between consecutive digit stimuli. Hence, it might be that tinnitus was present during the silent gaps, making the subjects more distracted. Finally, for each spoken digit in the conditions with background noise, the noise masker started 200 ms before onset and ended 200 ms after offset, which might be not long enough to have any effect on the secondary task performance (Andersson et al., 2000). Although the effect of several types of masking noise on cognitive performance in tinnitus patients is not yet clear (Andersson, Edsjö, Kaldo, & Westin, 2009; Andersson et al., 2002), this test may be adapted so that noise is presented during a longer period and at the most appropriate masking level for each participant in order to investigate how noise may distract attention from the tinnitus without having an adverse effect on speech recognition.

Nevertheless, the assumption that tinnitus may be more disturbing when it is perceived more, might be supported by the participants' subjective experience of listening effort. The subjective effort associated with speech understanding in different listening situations was questioned in both the subjects with tinnitus and the subjects from the control group. Although no significant differences in subjective effort were found for all listening situations, a trend towards more difficulties with speech understanding was observed for the subjects with tinnitus in especially quiet situations where one must converse with one person as well as in quiet situations while conversing with several persons. For situations with more background noise, subjective effort in the TG slightly decreased and the differences in subjective effort between the two groups became smaller. Recent epidemiologic research on NIT in young adults also showed that subjects with chronic tinnitus indicated more difficulties in quiet listening situations compared to subjects without tinnitus, as opposed to situations with background noise (Degeest, Keppler, et al., 2016). Therefore, in listening situations with more background noise, not only the presence of tinnitus may affect listening

effort since also subjects without tinnitus subjectively experience more difficulties with speech understanding in such listening situations.

Concerning the approach of this study, a few limitations should be mentioned. First, the study was limited by the small sample size. Hence, the statistical power to detect the effect of tinnitus and listening condition on the amount of listening effort with the current study sample was evaluated by means of a power analysis. It was found that the effect of tinnitus on the amount of listening effort can be detected with a power of 0.991, whereas the effect of listening condition on the amount of listening effort had a power of only 0.263. However, examining the effects of several listening conditions was not the scope of the manuscript and can probably be related to the specific group of normal-hearing young adults that was used in the present study. Nevertheless, a larger sample size in a future study would result in higher statistical power. Second, using a subgroup of normal-hearing young adults makes this study not representative for the whole tinnitus population. However, the present study included only normal-hearing young adults since it is well-known that age and hearing loss can have significant negative effects on listening effort (Degeest et al., 2015; Desjardins & Doherty, 2013; Gosselin & Gagne, 2010; Gosselin & Gagne, 2011; Pichora-Fuller et al., 1995; Pichora-Fuller & Singh, 2006; Schneider et al., 2002). Consequently, the present study was focused on a restricted group of participants. Moreover, the prevalence of chronic tinnitus in such a young age group is low (between 5.7% and 7.5%) (Degeest et al., 2014; Degeest, Keppler, et al., 2016; Hoffman & Reed, 2004), making it more difficult to include a large group of patients. However, using this type of participants can exclude a confounding influence of age and hearing loss. Further research on the effects of chronic tinnitus on listening effort, including a larger sample size as well as including older tinnitus patients and patients with hearing loss, is needed to explore the possible interaction between age, hearing loss and tinnitus. Thirdly, the present study only used the THI to measure the degree of tinnitus handicap. Although the THI is the most common used questionnaire and has a high reliability and construct validity (Newman et al., 1996), several limitations have been mentioned. The THI uses a three label category scale as well as assigning numbers, which limits its sensitivity and validity (Tyler, Oleson, Noble, Coelho, & Ji, 2007). Furthermore, the THI does not cover all aspects related to tinnitus distress. Despite that none of the participants indicated severe problems, future research should include other questionnaires

related to tinnitus distress or levels of depression or anxiety. Finally, no standardized tests for cognitive functions were included in the present study. Further research, including standardized tests for working memory, processing speed, and selective attention is needed to explore how these cognitive functions together contribute to a person's listening effort score.

In conclusion, the present study is a first exploration of listening effort in tinnitus patients showing that, independent of hearing sensitivity and tinnitus handicap, listening effort is increased in patients with tinnitus. Including a test for listening effort in clinical practice may therefore be useful to better understand the complaints about concentration related to speech recognition indicated by tinnitus patients. However, further research investigating the contribution of cognitive functioning to the amount of listening effort as well as research on the effects of masking noise on listening effort may be useful to increase insight in the assessment of tinnitus and the use of various treatment possibilities such as hearing aids and/or noise generators.

**Appendix**

The study described in chapter 7 (part II) concerns the effect of chronic tinnitus on the amount of listening effort in different listening conditions (i.e. quiet, SNR +2 dB and SNR -10 dB). To the best of our knowledge, no research exists pertaining to the effects of tinnitus on listening effort. Hence, the main goal of this study was to examine whether listening effort differs between normal-hearing young adults with chronic tinnitus ( $n=13$ ) and a matched-control group without tinnitus ( $n=13$ ). Regarding this purpose, a two-way ANOVA was used, which evaluates the outcome variable (i.e. listening effort scores) "between subjects", and whereby measurements are considered to be independent from one another (across all conditions). The rationale behind this approach is based on the considerable auditory contrast between the listening conditions.

Seen from another angle, each participant performed the dual-task paradigm in three different listening conditions (i.e. quiet, SNR +2 dB and SNR -10 dB), which can be considered as repeated-measures or a within-subjects factor. Hence, a mixed-design ANOVA with listening condition as the within-subjects factor and group (i.e. tinnitus group and matched-control group) as the between-subjects factor would be more appropriate to investigate the interplay between listening condition and the presence of chronic tinnitus and their effect on the amount of listening effort. In what follows, the results of such a mixed-design ANOVA will be presented.

Regarding the primary speech-recognition scores, the results of the mixed-design ANOVA showed the main effect of listening condition to be significant ( $F(1,48)=111.710$ ,  $p<0.001$ ). Pairwise comparisons with Bonferroni corrections showed a significant difference in speech-recognition scores between the quiet condition and the condition with a SNR of -10 dB, as well as between the condition with a SNR of +2 dB and the condition with a SNR of -10 dB ( $p<0.001$ ). The main effect of group and the interaction between listening condition and group were not significant ( $p>0.05$ ).

In case of listening effort, the results of the mixed-design ANOVA showed the main effect of group to be significant ( $F(1,24)=9.375$ ,  $p=0.005$ ), indicating that listening effort was significantly higher in the tinnitus group (Figure 7.8). The main effect of listening condition and the interaction between listening condition and group were not significant ( $p>0.05$ ).

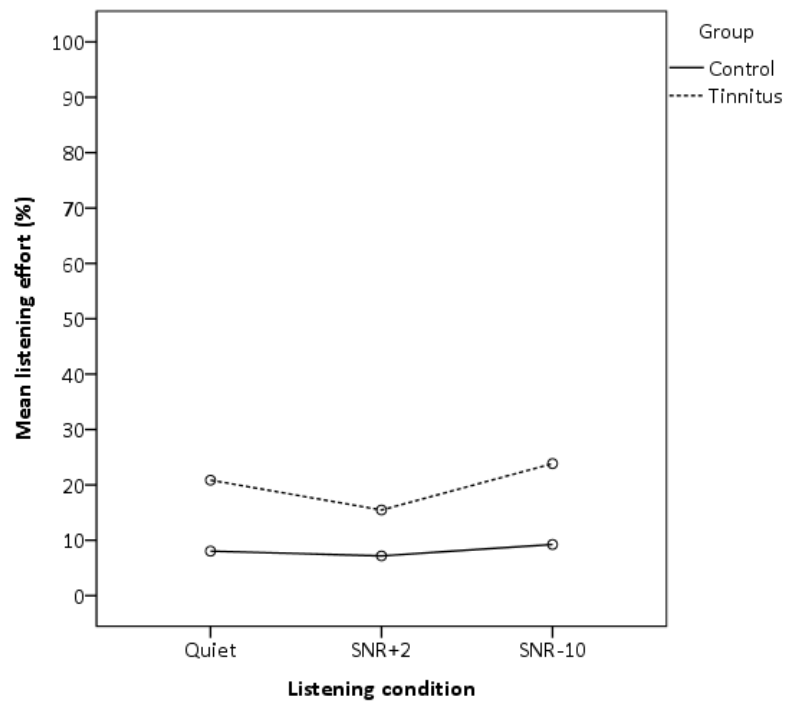
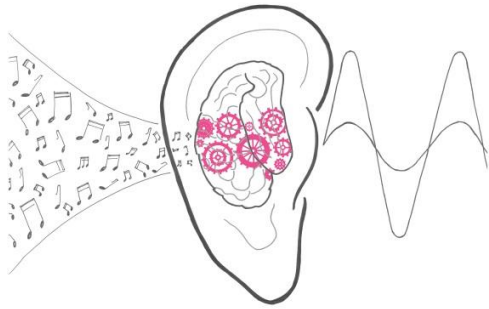


Figure 7.8 Mean listening effort (%) as a function of participant group and listening condition.

The results of the mixed-design ANOVA revealed no additional information as compared to the two-way ANOVA described in the study of chapter 7 (part II). It appears that in normal-hearing young adults, tinnitus significantly affects the amount of listening effort. However, the sample size of the present study is rather small so that further research investigating the effects of several listening conditions as well as different types of masking noise on listening effort is necessary. A discussion of the results and suggestions for further research are provided in 7.2.4.

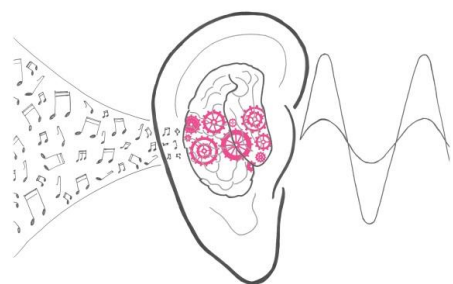






## **GENERAL DISCUSSION**





## CHAPTER 8

Discussion and future perspectives



The main objective of this thesis was to determine and describe the effects of leisure noise exposure on the auditory system in Flemish young adults, with special attention to the presence and impact of tinnitus. To achieve this objective, six studies were conducted and presented in three sections (chapter 5, 6 and 7). For each of those sections, the current chapter will provide a general overview of the results together with the strengths and limitations and some suggestions for future research.

### **8.1 Prevalence of noise-induced damage in Flemish young adults**

Identifying subjects at risk for acquiring hearing damage or hearing related symptoms such as tinnitus is very important in order to prevent future damage. Hence, insight in the prevalence of hearing damage and/or tinnitus as well as various factors that may be involved in the risk for acquiring such symptoms is important. In Flanders, however, there is a lack of epidemiologic data concerning hearing damage and tinnitus in young adults.

In this respect, **part I and part II of chapter 5** respectively described the prevalence of hearing damage and of both temporary and chronic tinnitus after leisure noise exposure in Flemish young adults. Based on the results of 517 young adults between 18 and 30 years, it was confirmed that they participate in several leisure activities, with a wide variation in attendance and estimated noise levels per activity. Especially nightclubs and music venues were found to present an increased risk as a result of the high noise levels. Regarding the evaluation of hearing status by means of pure-tone audiometry, no clinically significant hearing deteriorations were found among the young adults in this thesis. 15.7% showed subclinical OHC damage as measured by means of TEOAEs and DPOAEs. This confirmed that OAEs are an useful tool to identify subtle inner-ear changes caused by noise exposure (Keppler, 2010). Furthermore, except for age, no clear significant relations were found between the hearing status and variables that may influence the risk of noise-induced hearing damage (i.e. the amount of leisure noise exposure or attitudes towards noise, hearing loss and HPDs). Therefore, it was hypothesized that exposure to leisure noise during this period of life is too short to cause sufficient hearing loss (Smith et al., 2000). However, the effects of leisure noise may become noticeable over the long term as the presence of subclinical hearing loss measured by means of TEOAEs and DPOAEs was found to be significantly associated with increasing age.

In contrast to their hearing status, the majority of young adults reported to have experienced temporary tinnitus (68.5%) and even 6.4% already indicated chronic tinnitus due to leisure noise exposure. Moreover, results showed that young adults with chronic tinnitus had been exposed to higher noise levels during leisure activities. Furthermore, they reported significantly more concomitant hearing-related symptoms, such as difficulties with speech understanding. However, young adults with chronic tinnitus had more anti-noise attitudes and more often wore HPDs compared to subjects with temporary tinnitus and subjects without tinnitus. Increased levels of noise during leisure time may thus increase the risk of chronic tinnitus, though it can be suggested that once chronic tinnitus is present, it might serve as a trigger towards more awareness of the risks of noise and the importance of HPDs.

### **8.1.1 Strengths and limitations**

A summary of the strengths and limitations pertaining to the “prevalence of noise-induced damage in Flemish young adults” is provided in Table 8.1.

In addition to the existing prevalence data of noise-induced hearing damage and tinnitus in teenagers and university students that were collected through questionnaires (Gilles et al., 2012; Gilles et al., 2013), the results presented in chapter 5 may add useful information pertaining to the current situation in Flanders in terms of the effects of leisure noise on hearing of young people. Moreover, the present thesis collected data through questionnaires as well as by means of pure-tone audiometry and OAEs. This provides useful information concerning young adults’ subjective experiences of hearing as well as clinical information concerning their actual hearing status. Furthermore, the presence of hearing damage and tinnitus was also evaluated in relation to sociodemographic variables as well as young adults’ noise exposure levels and their risk-taking and protective behaviour with regard to noise. Not only may such information increase knowledge about the effects of leisure noise on the hearing of young adults, it can be useful to further optimize future preventive campaigns. For example, preventive campaigns may focus on tinnitus as a sign of overexposure, whereby it should be underlined that temporary tinnitus can be an indication of early hearing damage and can evolve into chronic tinnitus (Gilles et al., 2013). Since tinnitus is a symptom that can be clearly noticed after exposure to leisure noise, this might

serve as a trigger towards more awareness of the risks of leisure noise and the importance of HPDs.

A possible limitation of this part of the thesis is that convenience sampling was used, which might imply that the sample is not completely representative for the population of Flemish young adults. However, it was ensured that men and women were recruited from different regions in Flanders with a variation in age and employment status. Furthermore, subjects were excluded when they were exposed to noise 12 hours before the audiological examination, resulting in the exclusion of young adults exposed to noise at work (e.g. occupational noise or subjects working at noisy places such as nightclubs). Therefore, it may be possible that these subjects may have hearing loss or other hearing-related symptoms, which could not be detected by this study. Second, the studies presented in chapter 5 (part I and part II) are cross-sectional studies in which participants were evaluated at one moment in time. Hence, it is not possible to make causal inferences. The results can be influenced by factors specifically associated with the time-frame in which the study was conducted. For example, in Flanders, many educational campaigns have been conducted in recent years in order to emphasize the harmful effects of loud music on hearing (e.g. 'help ze niet naar de tuut'), which might have led to a change in attitudes towards noise, hearing loss and HPDs. Two Flemish studies evaluated the effect of hearing education programs on the attitudes of young people towards noise and HPDs using the Youth Attitude to Noise Scale (YANS) and the Beliefs About Hearing Protection and Hearing Loss (BAHPHL) instrument (Gilles, 2014; Keppler, Dhooge, Degeest, et al., 2015). Both studies found a significant decrease in several subscales of the YANS and BAHPHL after educating youth about the impact of noise on hearing, which implies a more negative attitude towards noise and more awareness of the benefits of wearing HPDs. Third, no noise measurements were conducted during leisure activities in which young adults participate, mainly due to logistical and financial challenges. Although individuals can make a reasonable estimate of the loudness of events they participate in (Beach et al, 2012a), the subjective estimation of loudness that was used might have led to inaccuracies in the calculation of the lifetime noise exposure level. However, no statements were made about the absolute noise levels, but only about the relative relation between the noise levels of the different activities and the presence of noise-induced hearing damage and tinnitus. Fourth, the use of HPDs per activity was questioned but not



taken into account in the calculation of the lifetime noise exposure level. However, no information was collected about how long someone has been wearing HPDs. Moreover, the majority of the subjects did not wear HPDs so that it is not possible to draw conclusions about the effectivity of wearing HPDs to protect hearing. Finally, with approximately 40% of the participants being employed, occupational noise may have been a confounding factor for the results found in this part of the thesis. However, only 15.3% reported occupational noise exposure and no significant difference in lifetime occupational noise exposure and the presence of noise-induced hearing damage or tinnitus was found. This result suggests that occupational noise exposure was not a major contributor for noise-induced damage or tinnitus. Furthermore, the effects of occupational noise may become noticeable over the long term, since the effects of noise exposure on hearing are the greatest during the first 10 to 15 years of exposure (American College of Occupational and Environmental Medicine, 2003). The average occupational noise exposure of the participants in this thesis was only 3.5 years. Nevertheless, it is not possible to completely rule out the effects of occupational noise.

Another point that should be considered is related to the finding that the majority of the subjects included in the study of chapter 5 (part I) had normal hearing as measured by pure-tone audiometry and both TEOAEs and DPOAEs. As mentioned by other research (e.g. Gilles et al., 2016), the usefulness of pure-tone audiometry and OAE measurements to detect early noise-induced damage can be questioned. Although OAEs are proved to be useful to identify and monitor inner-ear changes (e.g. Keppler, 2010; Lapsley Miller & Marshall, 2007), the OAE responses can vary as a result of some non-auditory factors, of which the most important are related to the probe placement, test parameters and the recording instrument (Keppler, 2010). Therefore, further optimization of the OAE technique, taking into account the influence of non-auditory factors, is necessary to enhance the reliability of OAEs to detect minimal cochlear changes (Keppler, 2010). Furthermore, recent animal studies suggest that synapses between hair cells and cochlear nerve terminals can be degraded by noise exposure, even when hair cells recover (i.e. cochlear synaptopathy) (Kujawa & Liberman, 2009). Hence, hearing loss can remain “hidden” because hearing thresholds return to normal (e.g. Lobarinas, Salvi, & Ding, 2013). As only pure-tone audiometry and OAE measurements were used to investigate the hearing status, no

conclusions can be made about the existence of possible cochlear synaptopathy in this group of young adults exposed to noise.

Table 8.1 A summary of the strengths and limitations pertaining to the “prevalence of noise-induced damage in Flemish young adults”.

Strengths	Limitations
<ul style="list-style-type: none"> <li>- Subjective and objective evaluation</li> <li>- Combination of several risk factors were taken into account</li> <li>- Additional information about the effects of leisure noise in Flemish young people</li> <li>- Useful information for future preventive campaigns</li> </ul>	<ul style="list-style-type: none"> <li>- Convenience sampling</li> <li>- Cross-sectional study design</li> <li>- No real life noise measurements</li> <li>- Influence of occupational noise</li> </ul>

### 8.1.2 Future perspectives

Based on the abovementioned strengths and limitations, perspectives for future research can be formulated.

First, longitudinal studies are needed to monitor the long-term effects of leisure noise exposure on hearing in young people. Also, the combined effects of both leisure noise exposure and occupational noise exposure should be taken into account during longitudinal research. Within such research, it will be important to include a large sample of young adults from the different regions in Flanders, with equal samples of men and women. For example, it will be interesting to investigate the effect of gender on the presence of tinnitus as it was found in the present thesis that gender is related to the presence of chronic tinnitus. Furthermore, longitudinal research is needed to evaluate how young adults' attitudes towards noise and the use of HPDs may change over time and how these attitudes can be related to their hearing status. For example, it can be investigated if subjects with pro-noise attitudes who do not use HPDs are more at risk for developing (subclinical) hearing loss. In addition, longitudinal research can also determine whether the experience of temporary or chronic tinnitus effectively leads to behavioural changes towards noise and the use of HPDs.

Second, real life measurements of the intensity levels at different leisure activities could be conducted in order to objectively identify activities with the highest risks of hearing damage. Using this information, the subjective loudness scale may be adapted to better agree with

real life intensity levels. Third, preventive campaigns should further focus on self-experienced symptoms such as tinnitus in order to make young adults more aware of the harmful effects of excessive noise exposure. The long-term effects of such campaigns may then be further investigated.

Finally, further research may also include the evaluation of hidden hearing loss, which takes into account the possible degeneration of the synapses between hair cells and cochlear nerve terminals as a result of noise exposure. Recent studies proposed the use of auditory brainstem responses (ABR), and in particular waveform I, as this represents the summed activity of the cochlear nerve fibers (e.g. Kujawa & Liberman, 2009). However, the use of ABR to diagnose cochlear synaptopathy in humans may be challenging because of inter-subject variability in ABR amplitudes due to several factors such as small SNRs or the heterogeneity in head size (Liberman, Epstein, Cleveland, Wang, & Maison, 2016). In order to reduce this variability, the study of Liberman et al. (2016) used electrocochleography, which makes it possible to determine the pre-synaptic summation potential (i.e. generated by the hair cells of the organ of Corti) as well as the action potential (i.e. ABR wave I). Animal studies showed that in case of noise-induced synaptopathy the amplitude of the summation potential remains stable while a reduction in the amplitude of the action potential is related to neural damage (Sergeyenko, Lall, Liberman, & Kujawa, 2013). To translate the knowledge to clinical practice, research is needed to optimize OAE measurements to detect subtle noise-induced damage as well as to establish reliable measures for detecting more centrally located deficits in noise-exposed subjects with normal pure-tone audiometry and OAE results.

## **8.2 Audiological assessment in tinnitus subjects**

When tinnitus is present, several tools are available to examine its (psychoacoustic) characteristics as well as associated factors such as hearing loss (Henry, Zaugg, et al., 2005; Holgers, Barrenäs, Svedlund, & Zöger, 2003). The use of these tools is important to evaluate the symptomatology of the tinnitus on the hand and can be used to prescribe and evaluate various therapeutic interventions on the other hand (Holgers et al., 2003).

In **part I of chapter 6**, the subjective characteristics of both temporary and chronic tinnitus after exposure to leisure noise were evaluated in 151 young Flemish adults between 18 and

30 years. First, it was found that the subjective characteristics of tinnitus were similar for temporary and chronic tinnitus. Both temporary and chronic tinnitus were mostly observed bilaterally as a continuous pure tone with a high pitch. This might suggest that the characteristics of tinnitus which one perceived after exposure to leisure noise cannot predict whether it will have a temporary or rather a chronic nature. Second, the psychoacoustical characteristics of their tinnitus were established in young adults reporting chronic tinnitus by means of a tinnitus analysis. In agreement with the subjective experience of chronic tinnitus, results of the tinnitus analysis showed that chronic tinnitus was mostly characterized as a continuous pure tone with an average pitch of 6.0 kHz. As far as maskability is concerned, psychoacoustic measurements showed low minimum masking levels (MMLs) in the subjects with chronic tinnitus, indicating that, in these subjects, tinnitus could be masked in the presence of relatively low levels of environmental sounds. Finally, hearing status was evaluated by means of pure-tone audiometry, TEOAEs and DPOAEs in the subjects with chronic tinnitus and compared with a matched control group. Hearing thresholds were better than 20 dB HL at all frequencies tested, except for three subjects (out of 7) with chronic tinnitus who met the criteria of a noise-induced threshold shift (NITS) (Niskar et al., 2001). However, from the subjects showing a NITS, the maximum hearing threshold exceeded 20 dB HL in only one subject. TEOAEs and DPOAEs were present in both the chronic tinnitus group and the control group, though reduced amplitudes of TEOAEs and DPOAEs were found in the subjects with chronic tinnitus. In contrast, a recent study of Gilles et al. (2016) could not demonstrate peripheral lesions in a group of young adults with chronic NIT and therefore suggested more centrally located deficits in tinnitus subjects. A possible explanation for these divergent results may be related to a difference in interpreting OAE results, since Gilles et al. (2016) used differences in the strength of TEOAEs and DPOAEs (i.e. dB SNR), whereas the present study used OAE amplitudes to evaluate the OHC function. A reduction in OAE amplitude may reflect OHC damage due to noise exposure (Śliwiska-Kowalska & Kotylo, 2007). As all subjects with chronic tinnitus included in the study of chapter 6 (part I) perceived their tinnitus after exposure to leisure noise, which is known to affect the cochlear hair cells, it might be suggested that OHC dysfunction may have played a role in the generation of tinnitus. Based on neurophysiology, it can be hypothesized that the reduced OAE amplitudes in the tinnitus group may have resulted in deprivation of input for the auditory nervous system and therefore have activated the process of

homeostatic plasticity (Møller, 2011d), leading to the perception of tinnitus. However, as no clinically significant decreased hearing thresholds were found, the presence of hidden hearing loss (i.e. cochlear synaptopathy) should also be considered (see 8.1.1). Previous research hypothesized that hidden hearing loss may also be involved in tinnitus because of the reduced neural output coming from the cochlea (e.g. Eggermont & Roberts, 2014; Schaette & McAlpine, 2011).

Identifying subjects with tinnitus is important since chronic tinnitus can have a significant impact on the quality of life. Knowledge about the factors that can affect the perceived impact of tinnitus will thus be necessary to detect tinnitus patients who may develop problems due to their tinnitus to such a degree that it affect their quality of life (Hoekstra et al., 2014). Until now, many studies have attempted to clarify the relation between tinnitus severity and various factors such as tinnitus characteristics or sociodemographics variables. However, contradicting results were reported due to methodological differences or shortcomings in the statistical analyses that were used (Hoekstra et al., 2014).

In **part II of chapter 6**, therefore, the (psychoacoustic) characteristics of tinnitus and tinnitus-related variables were determined in adults with chronic tinnitus in order to explore their relationship with tinnitus-related handicap. Based on the results of 81 adults between 18 and 73 years with chronic tinnitus, tinnitus awareness during the day and hyperacusis appeared to have significant effects on tinnitus-related handicap as measured by the Tinnitus Handicap Inventory (THI). The Hyperacusis Questionnaire (HQ) score was the strongest contributory factor to the THI score in the multiple regression analysis. Consistent with previous reports, it was suggested that the presence of hyperacusis in tinnitus patients increases the perceived impact of tinnitus (Falkenberg & Wie, 2012; Fioretti et al., 2013; Schecklmann et al., 2014), since both symptoms induce emotional and cognitive reactions (Henry, Dennis, et al., 2005; Wallhäußer-Franke et al., 2012). The THI and the HQ evaluate attentional and emotional reactions to symptoms associated with tinnitus and hyperacusis (Khalifa et al., 2002; Newman et al., 1996), which probably explains the strong association between the scores of both questionnaires. Tinnitus awareness during the day also had a significant effect on the perceived impact of tinnitus, though no significant relation was found with tinnitus loudness. According to previous reports, it can be hypothesized that psychoacoustically determined tinnitus loudness values are not suitable predictors for the

degree of tinnitus handicap, but that, on the other hand, both are related in the sense that perceived tinnitus handicap might influence the subjective experience of tinnitus loudness (Hoekstra et al., 2014; Kuk et al., 1990). Taking into account the mechanisms for tinnitus, activation of the non-classical auditory pathways may be involved in the relation between tinnitus-related handicap and both tinnitus awareness during the day and hyperacusis. It has been assumed that tinnitus distress is related to the activation of the non-classical auditory pathways, which provide a direct subcortical route to the amygdala (Møller, 2011d). Hence, when the subject is constantly aware of the tinnitus and undesirable emotional reactions occur, tinnitus will become a clinical problem through interconnections with the limbic system (Jastreboff, 2011; Kaltenbach & Manz, 2011; Møller, 2011d). In case of hyperacusis, also a secondary activation of the limbic and autonomic nervous system was proposed next to the high amplification within the auditory system (Jastreboff, 2011). In conclusion, these results suggest that assessing tinnitus awareness and hyperacusis would make it possible for clinicians to identify patients at risk of increased tinnitus-related handicap who may need more extensive counselling or therapy (Hoekstra et al., 2014).

### **8.2.1 Strengths and limitations**

A summary of the strengths and limitations pertaining to the “audiological assessment in tinnitus subjects” is provided in Table 8.2.

It is important to identify subjects at risk for acquiring tinnitus, and when chronic tinnitus is present, a careful and systematic diagnostic approach is crucial. The characteristics of both temporary and chronic tinnitus were evaluated in young adults (part I of chapter 6), which can help to identify different subforms of tinnitus and also to appraise the efficacy of specific interventions for tinnitus (Langguth, 2011a). To evaluate the audiological and (psychoacoustic) characteristics of tinnitus, the studies presented in chapter 6 (part I and part II) used current assessment procedures for tinnitus that are based on the recommendations described in several international guidelines (Langguth et al., 2007). In this respect, an extensive individual evaluation was provided. Moreover, the use of such uniform procedures can lead to a better comparison of diagnostic results between different clinics or treatment modalities (Henry, Zaugg, et al., 2005). In addition, factors that may influence the impact of chronic tinnitus were evaluated (e.g. sociodemographic variables or

the presence of hyperacusis) in part II of chapter 6, which can support clinicians to identify patients at risk of increased tinnitus-related handicap and who may need more extensive counselling or therapy. As multivariate analyses were used for this purpose, confounding influences could be excluded, so that only those factors showing unique combined effects on the level of handicap were identified.

A limitation of the study presented in part I of chapter 6 is related to the small sample of young adults with chronic tinnitus that were further evaluated. This small sample is mainly due to the fact that the prevalence of NIT in this population is rather small (6.6%). Furthermore, hearing loss is often associated with tinnitus and can affect the results of the OAE measurements (Keppler, Dhooge, Corthals, et al., 2010). The effects of the combination of both could not be investigated with the current sample of young adults as no clinically significant decreased hearing thresholds were found. Therefore, the audiological characteristics and hypothesis regarding the involvement of OHCs in the origin of leisure NIT cannot be generalized towards the whole population of subjects with tinnitus caused by noise. Another limitation concerns the use of the THI, which was used to measure the degree of tinnitus handicap in both part I and part II of chapter 6. Although the THI is the most commonly used questionnaire and has a high reliability and construct validity (Newman et al., 1996), several constraints have been mentioned. The THI uses a three label category scale as well as assigning numbers, which limits its sensitivity and validity (Tyler et al., 2007). However, the lack of a 'gold standard' for measuring tinnitus-related handicap is well known (Hoekstra et al., 2014). Furthermore, the study presented in part II of chapter 6 was also limited by the lack of including psychological factors. In the literature, the evaluation of psychological factors have been assumed to be important in subjects with tinnitus as they often report that their quality of life is impaired by symptoms such as frustration, annoyance, irritation, anxiety and depression (Langguth, 2011b; Tyler & Baker, 1983). High self-attenders, who tend to give more attention to somatic sensations, are found to be more depressed and more distressed due to tinnitus and have greater perceived tinnitus handicap (Newman et al., 1997). Anxiety and depression have been strongly linked to the presence of tinnitus and both have a complex relationship. For example, symptoms of depression may occur as a reaction to tinnitus, while a third condition (e.g. a traumatic experience) can also result in tinnitus and symptoms of depression (Landgrebe & Langguth,

2011; Langguth & Landgrebe, 2011). From a neurophysiological point of view, a close relationship between tinnitus and symptoms of anxiety and depression has been suggested through the activation of the non-classical auditory pathways, with evidence from imaging studies that the neural correlates for tinnitus and symptoms of anxiety and depression overlap in the limbic networks (e.g. the amygdala, hippocampus and hypothalamus) (for an overview see Kleinjung, 2011). However, the present thesis did not use questionnaires that evaluate levels of depression or anxiety so that no conclusions can be made about the contribution of these variables to the amount of tinnitus handicap. Furthermore, tinnitus handicap was evaluated only in patients seeking medical help as they all were consulting an otorhinolaryngologist. Therefore it was less evident to find any factors that could confine rather than increase problems due to tinnitus.

Table 8.2 A summary of the strengths and limitations pertaining to the “audiological assessment in tinnitus subjects”.

Strengths	Limitations
<ul style="list-style-type: none"> <li>- Subjective and objective evaluation of chronic tinnitus</li> <li>- Internationally accepted procedures were used</li> <li>- Statistical analysis: combined effects of several factors were evaluated</li> </ul>	<ul style="list-style-type: none"> <li>- Small sample of young adults with chronic tinnitus</li> <li>- Use of the THI</li> <li>- Only patients seeking medical help</li> </ul>

### 8.2.2 Future perspectives

Based on the abovementioned strengths and limitations, perspectives for future research can be formulated.

The clinical utility of OAEs in subjects with tinnitus induced by leisure noise needs further research. For example, follow-up of subjects with chronic tinnitus in order to monitor changes in OAE amplitudes. On the other hand, subjects with abnormal OAE amplitudes could be monitored to investigate the possibility of developing tinnitus over time. Other techniques to detect early noise-induced damage can also be included in the evaluation of subjects with NIT. As described in 8.1.2, techniques to detect neuronal degeneration may be useful as this was suggested to be involved in hearing difficulties in noisy listening situations as well as in tinnitus and hyperacusis (e.g. Eggermont & Roberts, 2014; Liberman et al., 2016;



Schaette & McAlpine, 2011). Furthermore, the impact of tinnitus on the quality of life should also be investigated in a general population, including subjects not seeking medical help for their problem, in order to identify also factors that could confine rather than increase problems due to tinnitus. Other factors such as levels of anxiety or depression can also be measured in order to evaluate their additional value to identify patients in need for intervention.

### **8.3 The evaluation of listening effort in a general population and in tinnitus subjects**

Recently, a test for measuring listening effort has been suggested as a useful tool to evaluate the mental effort associated with speech understanding. Age is an important factor to consider when studying listening effort, as it is known that age-related declines in peripheral hearing function as well as age-related declines in higher-level cognitive processes can exacerbate difficulties with speech understanding (Baltes & Lindenberger, 1997; Keppler, Dhooge, Corthals, et al., 2010; Larsby et al., 2005; Lindenberger & Baltes, 1994; Pichora-Fuller & Singh, 2006; Schneider et al., 2002; Tun et al., 2008).

In **part I of chapter 7**, a dual-task paradigm was used to measure listening effort. Furthermore, the effect of age on the amount of listening effort was examined in a general population of adults between 18 and 77 years. Results showed that, independent of hearing sensitivity, age is a significant determinant of listening effort, whereby listening effort increases with increasing age even when age-related variance in speech recognition is partialled out. Moreover, it was found that listening effort started to increase in the fourth decade of life. Previous research showed that acoustic stimulation activates also neurons in non-auditory brain regions next to the well-known activation of the classical auditory pathways. For example, an increased activation of working memory and attention-related cortical areas were found by neurophysiological studies evaluating the processes of spoken language in noisy listening situations (e.g. Wong et al., 2009). Therefore, it was hypothesized that a person's cognitive ability may have influenced the amount of listening effort. Three aspects of cognitive functioning have been reported to be important for speech understanding, namely working memory, processing speed and attention (Akeroyd, 2008; Pichora-Fuller et al., 1995). These functions decline with increasing age (Gunstad et al., 2006; Kemper et al., 2009; Salthouse, 1985, 1996; Singh-Manoux et al., 2012) with evidence from

previous research that these declines begin to manifest from the age of 45 years (Singh-Manoux et al., 2012). The age-related changes in cognitive functioning might thus explain the finding of the present study that listening effort starts to increase in the fourth decade of life.

Given the complaints associated with impaired concentration and increased effort during daily listening situations reported by tinnitus subjects, the effect of tinnitus on listening effort in normal-hearing young adults with chronic tinnitus was explored in **part II of chapter 7**. The dual-task test as described in part I was used to compare the performances of normal-hearing young adults with chronic tinnitus and a matched control group without tinnitus. Results revealed that subjects with tinnitus had to spend significantly more listening effort compared to the control group. Based on previous research, it was hypothesized that a shift of attention towards the tinnitus and an extra load on working memory by the presence of tinnitus (e.g. Andersson et al., 2000; Hallam et al., 2004; Hallam et al., 1984; McKenna, 1997; Rossiter et al., 2006; Stevens et al., 2007) may have reduced the cognitive capacity when performing several tasks simultaneously. Evidence for this assumption may be derived from imaging studies indicating that next to the well-known activation of several auditory regions, also non-auditory brain regions are involved in tinnitus (Rauschecker et al., 2010). Hence, tinnitus involves alterations in the brain areas mediating among others memory and attention (De Ridder et al., 2011), which may have reduced cognitive capacity and therefore resulted in increased listening effort in the tinnitus subjects.

In conclusion, measures of listening effort can provide a more comprehensive evaluation of hearing disability and might complement current clinical assessment tools such as pure-tone audiometry and speech-in-noise tests. Furthermore, including a test for listening effort in clinical practice may be useful to better understand the complaints about concentration related to speech recognition indicated by tinnitus patients.

### **8.3.1 Strengths and limitations**

A summary of the strengths and limitations pertaining to “the evaluation of listening effort in a general and specific population” is provided in Table 8.3.

A test for listening effort evaluates the mental effort associated with speech understanding, which can provide information over and beyond the standard speech-recognition outcomes. Moreover, the results of a dual-task test provide information about realistic listening situations as persons often need to listen while performing other tasks (Gosselin & Gagne, 2010). The effect of age and hearing sensitivity on the amount of listening effort was evaluated using several multiple regression models (part I of chapter 7). Multiple regression analyses take interdependencies between variables into account, making it possible to evaluate which variables have a unique predictive effect on listening effort. For example, it is well known that hearing sensitivity decreases with age, so that variables that have been found in studies performing univariate analyses only could be biased due to confounding effects. Furthermore, previous research regarding listening effort compared only younger adults with older adults, while it is well-known that also middle-aged adults often report difficulties with speech understanding in adverse listening conditions (Helfer & Vargo, 2009; Morrell et al., 1996). Considering age along a continuum rather than as discrete groups may provide more accurate information regarding the change in listening effort from young to older adults. In addition, results derived from participants of different ages can be used to apply this test in other research using various populations. Listening effort was also evaluated in subjects with tinnitus (part II of chapter 7), which was, to the best of our knowledge, the first study of its kind. Therefore, this study might address a gap in the present literature. Moreover, the effect of tinnitus on listening effort could clearly be determined since a homogeneous group of normal-hearing young adults was used, which can exclude a possible confounding influence of age-related cognitive declines and hearing loss.

A first limitation of the studies presented in chapter 7 (part I and part II) concerns the lack of using standardized cognitive tests. The literature repeatedly mentioned that cognitive functions such as selective attention and working memory are involved in the age-related effects on listening effort as well as the complaints that are often reported by tinnitus

patients (Andersson et al., 2000; Andersson & McKenna, 2006; Pichora-Fuller & Singh, 2006; Rossiter et al., 2006; Schneider et al., 2002; Stevens et al., 2007). Based on the results of the studies in chapter 7, a significant contribution of those cognitive functions on the amount of listening effort was suggested, though no standardized tests for the evaluation of working memory or selective attention were administered to support this hypothesis. Second, the study about the effects of tinnitus on listening effort (part II of chapter 7) was limited by the small sample size and the use of a subgroup of normal-hearing young adults makes this study not representative for the whole tinnitus population. However, as the overall prevalence of chronic tinnitus in such a young age group is low (between 5.7% and 7.5%) (Hoffman & Reed, 2004), it is difficult to include a large group of subjects.

Table 8.3 A summary of the strengths and limitations pertaining to “the evaluation of listening effort in a general and specific population”.

Strengths	Limitations
<ul style="list-style-type: none"> <li>- Additional information over the standard audiological measurements</li> <li>- First exploration of listening effort in tinnitus patients</li> <li>- Statistical analysis:               <ul style="list-style-type: none"> <li>- Combined effects of several factors were evaluated</li> <li>- Controlled study design: controlled for age and hearing thresholds</li> </ul> </li> <li>- Reference values available for different ages</li> </ul>	<ul style="list-style-type: none"> <li>- No standardized cognitive measurements</li> <li>- No representative information for the whole tinnitus population</li> </ul>

### 8.3.2 Future perspectives

Based on the abovementioned strengths and limitations, perspectives for future research can be formulated.

First, the cognitive correlates for speech processing and their possible relationship with listening effort are subjects of further study. More specific, further research including standardized tests for working memory, processing speed, and selective attention is needed to explore how these cognitive functions contribute to a person’s listening effort score. This would be especially useful in middle-aged adults as it was shown that listening effort increases significantly from the fourth decade of life onwards. Furthermore, the interference

of tinnitus and cognitive processing and the resulting impact on listening effort should be further explored.

In addition to standardized cognitive tests, cognitive sub-processes related to speech understanding can be evaluated through objective electrophysiological tests. Previous research that evaluated speech understanding in noise showed an increased activity in working memory and attention-related cortical areas (Wong et al., 2009) as well as an increased fronto-central EEG activity (Getzmann & Falkenstein, 2011). Hence, further research may include the use of cortical event-related potentials (ERPs) to evaluate the neural correlates underlying the perceptual and cognitive processes, as ERPs reflect the synchronous neuronal activity associated with sensory and cognitive processes. One study of Getzmann, Wascher, and Falkenstein (2015) found that older adults showed delayed attentional control and reduced speech understanding as indicated by alterations in the P1-N1-P2 complex and the N400. P1 and N1 components can be used to evaluate early stimulus processing, while P2 and N400 waves can provide information of subsequent processing as these later ERP components are related to processes on a higher level of perceptual and cognitive operations (Gaillard, 1988). Besides, alterations in the N1-P2 responses in tinnitus patients are also mentioned in literature (e.g. Kadner et al., 2002). The P300 ERP has also been suggested as an index to evaluate listening effort as this response is highly dependent on the cognitive context in which a stimulus occurs as well as on the level of attention and arousal. Moreover, the P300 ERP may be useful in the evaluation of tinnitus because of the overlap between the P300-related brain areas and those that may be involved in tinnitus (e.g. the parahippocampus and insula) (Gabr, El-Hay, & Badawy, 2011; Gilles, 2014). However, the specific underlying brain areas of ERPs are still under debate and also their use in the evaluation of listening effort as well as tinnitus patients is still not clear. In addition, EEG measurements can be used to evaluate potential neuronal correlates of specific cognitive processes. Specifically, alpha activity has been proposed as useful when evaluating speech understanding in noise as it is hypothesized to reflect the functional inhibition associated with effortful listening (Sauseng & Klimesch, 2008). However, it is not clear how these techniques reflect the kind of mental exertion so that further research is needed to optimize these techniques to measure listening effort as well as to include several individual factors that can lead to large variability (e.g. McGarrigle et al., 2014).

Second, it is well-known that tinnitus patients may profit from background noise since it can mask their tinnitus (Jastreboff, 2011; Vernon & Meikle, 2003). Although not detected in the present thesis, it can be hypothesized that some levels of background noise may be beneficial for tinnitus subjects in terms of listening effort. The effect of several types of masking noise on cognitive performance in tinnitus patients is, however, not yet clear (Andersson et al., 2009; Andersson et al., 2002). Further research may therefore be directed to the effects of background noise on the amount of listening effort. Consequently, research may consider whether various treatment possibilities for tinnitus patients such as hearing aids and/or noise generators can positively affect the amount of listening effort. Finally, since age and the presence of hearing disorders are known influencing factors for listening effort, further research may include older tinnitus patients and patients with hearing loss in order to explore the possible interaction between age, hearing loss and tinnitus.

Considering the studies presented in chapter 5, 6 and 7, the effects of noise exposure on hearing and the perception of tinnitus may involve both peripheral alterations as well as alterations in auditory and non-auditory brain areas. However, it should be mentioned that the hypotheses regarding the involvement of the central components are based on literature as no specific measurements were included to support these hypotheses. Nevertheless, the involvement of the central auditory and non-auditory brain areas may somewhat be supported by the finding that listening effort was increased in normal-hearing tinnitus subjects. A test for listening effort evaluates the cognitive processes required for speech understanding (Broadbent, 1958) and therefore provides information beyond the traditional speech audiometry outcomes. Hence, it can be suggested that the use of the traditional audiological test battery remains important in the evaluation of noise-exposed subjects, but may be supplemented by other techniques that can detect possible alterations in the higher-order processing of sounds. As assumed by literature, techniques that can detect neuronal degeneration and therefore hidden hearing loss should be further explored in noise-exposed subjects. In addition, techniques that evaluate the central sensory and cognitive processes involved in speech understanding and listening effort should be further explored.

#### **8.4 General conclusion**

Considering the increased concern about leisure noise exposure on hearing in especially young people, the main objective of this thesis was to determine and describe the effects of leisure noise exposure on the auditory system in Flemish young adults, with special attention to the presence and impact of tinnitus. Based on the studies described in this work, insights on various areas have been provided:

- Tinnitus appears to be the main symptom reported by Flemish young adults after exposure to leisure noise, whereas the occurrence of hearing loss was found to be limited. Furthermore, tinnitus as a self-experienced symptom proved to be important for young adults' risk-taking and protective behaviour with regard to noise.
- When chronic tinnitus is experienced, the comorbidity of hyperacusis as well as tinnitus awareness during the day are important factors that can influence the perceived severity of tinnitus.
- A test for listening effort can provide useful information about difficulties with speech understanding in different listening situations. Especially age was found to be an important factor to consider, mainly due to age-related changes in the cognitive correlates for speech processing. Furthermore, tinnitus appears to affect the amount of listening effort as it was shown that young adults with chronic tinnitus and normal hearing had to spend more listening effort in several listening situations.

These results underpin the importance of educating young adults about the risks of noise during leisure activities, with special attention to tinnitus as a sign of overexposure. Such information may be used to implement in the existing preventive campaigns. In addition, assessing several variables associated with tinnitus would make it possible to identify patients at risk of increased tinnitus-related handicap who need more extensive counselling or therapy. Finally, a test for listening effort can provide useful information complementary to the traditional audiological assessment procedures. Further research can focus on the optimization and implementation of this test in the assessment of tinnitus.





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## **CURRICULUM VITAE**

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Sofie Degeest werd geboren op 15 januari 1989 te Gent.

Na het afronden van haar middelbare studies Moderne Talen-Wetenschappen aan het Sint-Gertrudiscollege te Wetteren in 2007, startte ze aan de opleiding Logopedische en Audiologische Wetenschappen aan de Universiteit Gent. In 2011 behaalde ze met grote onderscheiding het diploma van Master in de Logopedische en Audiologische Wetenschappen, afstudeerrichting audiologie. In november 2011 startte ze haar doctoraatsonderzoek aan de Universiteit Gent onder leiding van Prof. Dr. Paul Corthals en Prof. Dr. Hannah Keppler.

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**Bijkomende opleidingen**


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- Workshop Endnote, biomedische bibliotheek, Universiteit Gent, 2012
- Cursus Statistiek, Inleiding tot SPSS, Universiteit Gent, Doctoral School of Life Science and Medicine, 2012
- Cursus Statistiek, Introductory Statistics, Instituut voor Permanente Vorming in de Wetenschappen, Universiteit Gent, Doctoral School of Life Science and Medicine, 2012
- Advanced English Writing Skills, Universitair Talencentrum, Universiteit Gent, Doctoral School of Life Science and Medicine, 2013
- Cursus Statistiek, Analysis of Variance, Instituut voor Permanente Vorming in de Wetenschappen, Universiteit Gent, Doctoral School of Life Science and Medicine, 2014
- Cursus Statistiek, Applied linear regression, Instituut voor Permanente Vorming in de Wetenschappen, Universiteit Gent, Doctoral School of Life Science and Medicine, 2015
- Practicumtraining, Universiteit Gent, 16 september 2015
- Basisassistententraining, Universiteit Gent, 30 september 2015

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**A1 Publicaties**


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- Degeest S., Corthals P., Vinck B., & Keppler H. (2014). Prevalence and characteristics of tinnitus after leisure noise exposure in young adults. *Noise and health*, 16(68), 26-33.
- Degeest S., Keppler H., & Corthals P. (2015). The effect of age on listening effort. *Journal of Speech, Language, and Hearing Research*, 58(5), 1592-1600.
- Keppler H., Dhooge I., Degeest S., & Vinck B. (2015). The effects of a hearing education program on recreational noise exposure, attitudes and beliefs toward noise, hearing loss, and hearing protector devices in young adult. *Noise and Health*. 17(78), 253-262.
- Degeest S., Corthals P., Dhooge I., & Keppler H. (2016). The impact of tinnitus characteristics and associated variables on tinnitus-related handicap. *The Journal of Laryngology & Otology*, 130(01), 25-31.
- Degeest S., Keppler, H., Corthals, P., Clays, E. (2017). Epidemiology and risk factors for tinnitus after leisure noise exposure in Flemish young adults. *International Journal of Audiology*, 2017, 56, 121–129.



- Degeest, S., Clays, E., Corthals, P., & Keppler, H. (2017). Epidemiology and risk factors for leisure noise-induced hearing damage in Flemish young adults. *Noise and Health*, 19(86), 10-19.
- Degeest S., Keppler H., & Corthals P. (2016). The effect of tinnitus on listening effort in young adults. *Journal of Speech, Language, and Hearing Research*, accepted for publication September 12, 2016.
- Keppler H., Dhooge I., & Degeest S. (2016). The relationship between tinnitus pitch and parameters of audiometry and distortion product otoacoustic emissions. *The Journal of Laryngology & Otology*, submitted.
- Degeest S. & Keppler H. (2016). Test-retest reliability of questionnaires regarding attitudes and beliefs towards noise, hearing loss and hearing protector devices in young adults. *Noise and Health*, in preparation.
- Keppler H., Heyse J., Vinck B. & Degeest S. (2016). Organizers' knowledge and opinion towards the Flemish legislation of noise exposure at music festivals. *Noise and Health*, in preparation.
- Keppler H., Lampo E., Bockstael A., Degeest S. & Botteldooren D. (2016). Probe fitting for transient evoked otoacoustic emission measurements: subjective evaluation and effect on response and noise amplitudes. *Ear and Hearing*, in preparation.

#### **Internationale voordrachten en wetenschappelijke congressen**

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- Tinnitus Research Initiative conference, Brugge, België, 13-16 juni 2012. Degeest S., Corthals P, Vinck B & Keppler H. Prevalence and characteristics of tinnitus after noise exposure during recreational activities. (poster)
- Tinnitus Research Initiative conference, Brugge, België, 13-16 juni 2012. Keppler H, Corthals P, Vinck B & Degeest S. Results of otoacoustic emissions and efferent suppression in subjects with chronic tinnitus after noise exposure during recreational activities. (poster)
- 11th European Federation of Audiology Society congress, Budapest, Hongarije, 19-22 juni 2013. Van Lierde K, Vinck B, Maes L, Keppler H, Degeest S & Corthals P. Bachelor and

Master of Science in Logopaedic and Audiological Sciences - main subject Audiology at Ghent University (Belgium). (poster)

- International Tinnitus Seminar, Berlin, Germany; 21-24 Mei 2014. Degeest S, Corthals P, Dhooge I & Keppler H. Do Tinnitus characteristics have an impact on its subjective experience? (oral presentation)
- B-Audio Meeting, Brugge, België, 14 November 2014. Degeest S, Clays E, Corthals P & Keppler H. Epidemiology of tinnitus after leisure noise exposure in young adults. (oral presentation)
- European Federation of Audiology Societies, 12th Congress, Istanbul, Turkey, 27-30 Mei 2015. Keppler H, Dhooge I, & Degeest S. Relationship between tinnitus pitch and hearing loss in patients with tinnitus. (oral presentation)
- International Conference on Hyperacusis, Londen, United Kingdom, 9-10 Juli 2015. Degeest S, Corthals P, Dhooge I & Keppler H. The presence of hyperacusis in tinnitus patients – which factors are important? (oral presentation)
- Care of the Professional Voice, 45th Annual Symposium, Philadelphia, USA, 1-5 Juni 2016. D'haeseleer E, Claeys S, Meerschman I, Bettens K, Degeest S, Dijckmans C, De Smet J, Luyten A & Van Lierde K. Voice symptoms and risk factors for developing voice disorders in future musical actors. (oral presentation)
- 33<sup>rd</sup> World Congress of Audiology, Vancouver, USA, 18-21 September 2016. Degeest S, Keppler H, & Corthals P. Cognitive ability in relation to listening effort. (poster)
- 33<sup>rd</sup> World Congress of Audiology, Vancouver, USA, 18-21 September 2016., Keppler H, Clinckaert K, Corthals P & Degeest S. The effect of hearing aids on listening effort. (poster)
- ENT/SASLHA/SAAA Congress 2016, Johannesburg, South-Africa, 8-10 Oktober 2016. Keppler H., Vermeersch I., Vinck B. & Degeest S. Short-term test-retest reliability of the olivocochlear efferent reflex strength in normal-hearing subjects (presentation)
- B-Audio Meeting, Leuven, België, 19 November 2015. Degeest S, Keppler H & Corthals P. Listening effort in normal-hearing young adults with chronic tinnitus. (oral presentation).

**Nationale voordrachten en wetenschappelijke congressen**

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- Wetenschapsdag Universiteit Gent, Gent, België, 14 maart 2012. Degeest S, Corthals P & Keppler H. Prevalence and characteristics of tinnitus following recreational noise exposure. (poster)
- Bijeenkomst Vereniging van Onafhankelijke Audiologen en Audiciens, Grimbergen, België, 18 april 2012. Degeest. S. Tinnitus, prevalentie, oorzaken en audiologische testbatterij. (presentatie op uitnodiging van de organisatoren)
- VTI Waregem, België VTI Waregem, 24 april 2012. Degeest S. Invloed van lawaai op het gehoor. (presentatie)
- VTI Waregem, België, 10 januari 2013. Degeest S. Invloed van lawaai op het gehoor. (presentatie)
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#### **Wetenschappelijke onderscheidingen**

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- Prijs Professor Van Helmont  
Universiteit Gent, 15 oktober 2011

#### **Onderwijservaring**

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- Participatie aan de lessen ‘Basisbegrippen audiologie 1’ (Partim tonale audiometrie en maskeren), 1<sup>e</sup> bachelor Logopedische en audiologische wetenschappen Universiteit Gent
- Participatie aan de lessen ‘Basisbegrippen audiologie 2 met inbegrip van practica’ (Partim casuïstiek en Practica tonale audiometrie, spraakaudiometrie, OAEs en OTIS virtual patient), 2<sup>e</sup> bachelor Logopedische en audiologische wetenschappen Universiteit Gent – afstudeerrichting logopedie, audiologie en schakel tot logopedie
- Participatie aan de lessen ‘Prothetische audiologie’ (Practica oorafdrukken en hoortoestelfitting), 3<sup>e</sup> bachelor Logopedische en audiologische wetenschappen Universiteit Gent – afstudeerrichting audiologie en schakel tot audiologie

- Participatie aan de lessen ‘Klinische audiologie’ (Practica ABR en tinnitusanalyse, Partim casuïstiek, Partim efferente suppressie van OAEs), 3<sup>e</sup> bachelor Logopedische en audiologische wetenschappen Universiteit Gent – afstudeerrichting audiologie
- Participatie aan de lessen ‘Preventieve audiologie’ (Partim pathofysiologie en geluidsnormen voor muziekactiviteiten, Begeleiden groepswork rond de preventie van lawaai op recreatief en professioneel vlak), 3<sup>e</sup> bachelor Logopedische en audiologische wetenschappen Universiteit Gent – afstudeerrichting audiologie
- Participatie in de praktische ondersteuning, organisatie en begeleiding van de stages bachelor en master Logopedische en Audiologische wetenschappen – afstudeerrichting audiologie

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- Conings Sare, Mening van Vlaamse ouders over het risico op lawaaiëinduceerd gehoorverlies bij tieners, Promotor: Prof. Dr. Corthals P. – externe promotor: Drs. Degeest S., Hogeschool Gent, academiejaar 2013-2014.
- Vanthomme Simon, De invloed van lawaai blootstelling in de vrije tijd op het gehoor bij jongeren tussen 18 en 30 jaar nagaan, Promotor: Dr. Keppler H. – Copromotor: Drs. Degeest S., Universiteit Gent, academiejaar 2014-2015.

- Vandenbroucke Anna, Beroepsblootstelling aan lawaai in productieafdelingen van een non-ferro bedrijf, Promotor: Dr. Keppler H. – Copromotor: Drs. Degeest S., Universiteit Gent, academiejaar 2014-2015.
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- Claes Sofie en Vandermaelen Anje, Bruikbaarheid van de luisterinspanningstest in de detectie van vroegtijdige lawaaischade, Promotor: Dr. Keppler H. – Copromotor: Drs. Degeest S., Universiteit Gent, academiejaar 2015-2016.
- Vermeersch Ine, Contralateraal akoestische stimulatie van transiënt geëvokeerde otoakoestische emissies: normatieve data en test-hertest betrouwbaarheid, Promotor: Dr. Keppler H. – Copromotor: Drs. Degeest S., Universiteit Gent, academiejaar 2015-2016.
- Devos Geraldine, Evaluatie van een centraal auditieve en vestibulaire testbatterij, Promotor: Dr. Keppler H. – Copromotor: Drs. Degeest S., Universiteit Gent, academiejaar 2015-2016.
- Danneels Maya, Optimaliseren en valideren van een centraal auditieve testbatterij bij kinderen met auditieve verwerkingsstoornissen, Promotor: Dr. Keppler H – Copromotor: Drs. Degeest. S, Universiteit Gent, academiejaar 2016-2017.
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- De Kegel Eva en Van der Borghht Caroline, Bruikbaarheid van de luisterinspanningstest in de detectie van vroegtijdige lawaaischade, Promotor: Dr. Keppler H.– Copromotor: Prof. Dr. Dhooge I. en Drs. Degeest. S, Universiteit Gent, academiejaar 2016-2017.
- Lavaert Lotte en Van Cauwenberghe Julie, Implementatie van een cognitieve testbatterij in de assessment van kinderen met een CI , Promotor: Prof. Dr. Dhooge I. – Copromotor: Drs. Kriger S. en Drs. Degeest S.

**Andere**

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- Audiologische poliklinische consultaties bij patiënten met tinnitus. Dienst Neus-, Keel- en Oorheelkunde UZ Gent.





Beste,



Naar aanleiding van een doctoraatsonderzoek aan de Universiteit Gent, voeren wij een onderzoek naar lawaai-blootstelling in de vrije tijd en de effecten ervan op het gehoor.

Hierbij gaat het over activiteiten zoals het bijwonen van concerten, festivals of sportevenementen, het gaan naar fuiven, discotheken of de bioscoop, het beluisteren van muziek via een mp3-speler, spelen van een muziekinstrument, spelen in een band of orkest, het gebruik van luidruchtig gereedschap, enz.

Wij willen u dan ook vragen deze vragenlijst eerlijk en naar waarheid in te vullen. Er is telkens slechts één antwoord mogelijk, tenzij anders vermeld. Het invullen van de vragenlijst duurt ongeveer 10 minuten.

Na het invullen van de vragenlijst slaat u deze op met volgende naam: **uw initialen\_datum waarop u de vragenlijst hebt ingevuld (vb. sdg\_20121107)**. Daarna stuurt u de vragenlijst per mail terug naar [sofie.degeest@ugent.be](mailto:sofie.degeest@ugent.be)

Hartelijk dank voor uw medewerking!

Drs. Sofie Degeest  
Prof. Dr. P. Corthals  
Dr. H. Keppler

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### We starten met enkele algemene vragen.

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1. Woonplaats (postcode):

.....

2. Geboortedatum (dd/mm/jjjj):

.....

3. Geslacht:

Man

Vrouw

4. Welk van volgende beschrijvingen komt het best overeen met uw beroepsstatuut?

U bent scholier | student | in opleiding | doctoraatsstudent (**Ga naar vraag 5**)

U bent werkloos (**Ga naar vraag 6**)

U bent huisman of huisvrouw (**Ga naar vraag 6**)

U bent arbeidsongeschikt (**Ga naar vraag 6**)

U heeft een voltijdse of deeltijdse betrekking (**Ga naar vraag 7**)

U heeft een betrekking maar bent dit werk nog niet begonnen (**Ga naar vraag 7**)

Andere: ..... (**Ga naar vraag 8**)

## 5. Welke studierichting volgt u?

- Secundair onderwijs – ASO
- Secundair onderwijs – TSO
- Secundair onderwijs – BSO
- Secundair onderwijs – KSO
- Postsecundair onderwijs (7<sup>e</sup>, 8<sup>e</sup> jaar,...)
- Voortgezet, niet-hoger onderwijs (Syntra-, VDAB- opleidingen,...)
- Hogeschool opleiding (academische of professionele bachelor)
- Universitaire opleiding
- Doctoraat
- Andere (specificeer): .....

**Ga vervolgens verder met vraag 9.**

## 6. Hoe lang bent u reeds werkloos / huisman of huisvrouw / arbeidsongeschikt?

- < 1 jaar
- 1 – 2 jaar
- > 2 jaar

**Ga vervolgens verder met vraag 8.**

## 7. Welk beroep oefent u uit?

## ❖ Zelfstandige

- Landbouwer
- Ambachtsman, handelaar
- Industrieel, groothandelaar
- Vrij beroep of beroep waarvoor kwalificatie nodig is (dokter, advocaat, expert boekhouder...)

## ❖ Bediende

- Lid van de algemene directie, hoger kaderlid (vb. directeur, beheerder, ...)
- Middenkader, geen deel uitmakend van de algemene directie (vb. hoofd van een dienst of afdeling,...)
- Andere bedienden
  - Met hoofdzakelijk kantoorwerk (vb. secretaresses, assistenten, ...)
  - Geen kantoorwerk (vb. verpleegsters, onderwijzers, politiemannen, ...)

## ❖ Arbeider

- Geschoold arbeider
- Ongeschoold arbeider

8. Het hoogste diploma dat u behaald heeft (ofwel via dagonderwijs of avondonderwijs)?

- Lager onderwijs (lagere school of geen enkel diploma)
- Secundair onderwijs – ASO
- Secundair onderwijs – TSO
- Secundair onderwijs – BSO
- Secundair onderwijs – KSO
- Postsecundair onderwijs (7<sup>e</sup>, 8<sup>e</sup> jaar,...)
- Voortgezet, niet-hoger onderwijs (Syntra-, VDAB- opleidingen,...)
- Bachelor (academisch of professioneel)
- Master
- Doctoraat
- Andere (specifieer): .....

9. Rookt u of heeft u gerookt?

- Ik heb vroeger gerookt, maar nu niet meer
- Ik rook momenteel en ben een regelmatige roker (dagelijks)
- Ik rook momenteel en ben een occasionele roker (minder dan dagelijks)
- Ik heb nooit gerookt

10. Heeft u een chronische ziekte of andere van onderstaande aandoeningen? (*meerdere antwoorden mogelijk*)

- Hart- en vaatziekten
- Diabetes
- Tandaandoening
- Schildklier-aandoening
- Frequent doormaken van infecties
- Frequent doormaken van middenoorontstekingen
- Problemen met de sinussen (sinusitis,...)
- Letsel aan het hoofd (val, (verkeers)ongeval, voorwerp...)
- Erfelijke aandoening (specifieer): .....
- Andere (specifieer): .....
- Geen van bovenstaande

11. Hoe vindt u uw algemene gezondheidstoestand?

- Zeer goed
- Goed
- Middelmatig
- Slecht
- Zeer slecht

---

**Hierna volgen enkele vragen met betrekking tot uw gehoor**

---

12. Heeft u ooit een ooperatie ondergaan? (vb.: plaatsen van buisjes, operatie aan het trommelvlies of de gehoorbeentjes, ...)

- Ja  
 Neen  
 Geen idee

13. Werd uw gehoor ooit getest?

- Ja  
 Neen (**Ga naar vraag 15**)

14. Werd er toen een gehoorverlies vastgesteld?

- Ja  
 Neen

15. Hoe goed vindt u uw gehoor?

- Ik hoor heel goed (**Ga naar vraag 18**)  
 Ik hoor goed (**Ga naar vraag 18**)  
 Ik hoor minder goed (of er werd reeds een gehoorverlies vastgesteld) (**Ga naar vraag 16**)

16. Aan welk oor hoort u minder goed?

- Aan mijn rechteroor  
 Aan mijn linkeroor  
 Aan beide oren  
 Geen idee

17. Wat is volgens u de reden van uw verminderd gehoor? (*Meerdere antwoorden mogelijk*)

- Ik heb een aangeboren slechthorendheid  
 Ik heb in mijn jeugd frequent (midden)oorontstekingen doorgemaakt en hoor daardoor minder goed  
 Ik heb een verminderd gehoor sedert een trauma aan het hoofd (val, (verkeers)ongeval, voorwerp..)  
 Ik heb een verminderd gehoor sedert een ziekte  
 In mijn familie (broer(s), zus(sen), vader of moeder) komt slechthorendheid voor  
 Ik gebruikte medicijnen waardoor een verminderd gehoor is opgetreden  
Welke medicijnen: .....
- Ik ben tewerkgesteld in lawaai waardoor ik minder goed hoor  
 Tijdens recreatieve activiteiten (fuiwen, festivals, concerten, sportevenementen...) of tijdens het beluisteren van mijn MP3-speler word ik blootgesteld aan lawaai, waardoor ik minder hoor  
 Ik weet het niet  
 Andere (specifieer): .....

18. Kruis bij elke stelling telkens 1 vakje aan

	Altijd	Vaak	Soms	Zelden	Nooit
Heeft u wel eens moeilijkheden om alles goed te verstaan?					
In rustige omstandigheden met hoogstens 2 andere personen?	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
In rustige omstandigheden met veel andere mensen?	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
In rumoerige omstandigheden?	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

**Op de volgende pagina's volgen enkele vragen met betrekking tot lawaai blootstelling en gehoorbescherming**

19. In volgende tabel geeft u aan hoe vaak u deelneemt aan de opgesomde activiteiten. Dit mag een ruwe schatting zijn.

- U duidt aan hoe vaak u aan de opgesomde activiteiten deelneemt. Indien u 'jaarlijks', 'maandelijks' of 'wekelijks' aangeeft, geeft u ook weer hoeveel keer per jaar, per maand of per week u gemiddeld deelneemt aan de activiteit. Indien u 'nooit' aangeeft, hoeft u de volgende kolommen niet in te vullen.
- Vervolgens geeft u in de kolom 'aantal uren per sessie' weer hoelang u per keer gemiddeld spendeert aan de activiteit.
- Daarna geeft u in de kolom 'totaal aantal jaren' het aantal jaren dat u de activiteit reeds uitvoert.
- In de voorlaatste kolom geeft u per activiteit een schatting van de luidheid; u omcirkelt hiervoor het best passende cijfer.

Geschatte luidheid:

- 1 = geluidsniveau van een normale conversatie
- 2 = geluidsniveau van een luide conversatie
- 3 = geluidsniveau waarbij u moet roepen over 1 meter om gehoord worden
- 4 = geluidsniveau waarbij u moet roepen over een kleine afstand om gehoord te worden
- 5 = geluidsniveau dat communicatie onmogelijk maakt

- Ten slotte geeft u in de laatste kolom aan of u tijdens de activiteit gehoorbescherming gebruikt.

**Voorbeeld:**

Activiteit	a. Frequentie					b. Aantal uren per sessie	c. Totaal aantal jaren	d. Geschatte luidheid	e. Gehoorbescherming		
	Nooit	Jaarlijks (+hoeveel keer per jaar)	Maandelijks (+hoeveel keer per maand)	Wekelijks (+hoeveel keer per week)	Dagelijks				Ja	Soms	Neen
Vb. Concerten, festivals of optredens	<input type="checkbox"/>	<input checked="" type="checkbox"/> 3	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	5	2	4	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>

Activiteit	a. Frequentie								b. Aantal uren per sessie	c. Totaal aantal jaren	d. Geschatte luidheid					e. Gehoorbescherming		
	Nooit	Jaarlijks (+hoeveel)		Maandelijks (+hoeveel)		Wekelijks (+hoeveel)		Dagelijks			1	2	3	4	5	Ja	Soms	Neen
Spelen in een band of orkest	<input type="checkbox"/>	<input type="checkbox"/>	...	<input type="checkbox"/>	...	<input type="checkbox"/>	...	<input type="checkbox"/>	.....	.....								
Bespelen van een muziekinstrument Welk instrument:.....	<input type="checkbox"/>	<input type="checkbox"/>	...	<input type="checkbox"/>	...	<input type="checkbox"/>	...	<input type="checkbox"/>	.....	.....								
Luisteren naar een draagbaar audiosysteem via hoofdtelefoon of oordopjes (vb. mp3-speler)	<input type="checkbox"/>	<input type="checkbox"/>	...	<input type="checkbox"/>	...	<input type="checkbox"/>	...	<input type="checkbox"/>	.....	.....								
Luisteren naar een draagbaar audiosysteem via luidsprekers	<input type="checkbox"/>	<input type="checkbox"/>	...	<input type="checkbox"/>	...	<input type="checkbox"/>	...	<input type="checkbox"/>	.....	.....								
Televisie kijken	<input type="checkbox"/>	<input type="checkbox"/>	...	<input type="checkbox"/>	...	<input type="checkbox"/>	...	<input type="checkbox"/>	.....	.....								
Naar de bioscoop of het theater gaan	<input type="checkbox"/>	<input type="checkbox"/>	...	<input type="checkbox"/>	...	<input type="checkbox"/>	...	<input type="checkbox"/>	.....	.....								
Uitgaan naar een discotheek, fuif of danscafé	<input type="checkbox"/>	<input type="checkbox"/>	...	<input type="checkbox"/>	...	<input type="checkbox"/>	...	<input type="checkbox"/>	.....	.....								
Het bijwonen van festivals, concerten of optredens	<input type="checkbox"/>	<input type="checkbox"/>	...	<input type="checkbox"/>	...	<input type="checkbox"/>	...	<input type="checkbox"/>	.....	.....								
Sportevenementen (vb. basketbal, voetbal,...)	<input type="checkbox"/>	<input type="checkbox"/>	...	<input type="checkbox"/>	...	<input type="checkbox"/>	...	<input type="checkbox"/>	.....	.....								
Gebruik van luidruchtig gereedschap	<input type="checkbox"/>	<input type="checkbox"/>	...	<input type="checkbox"/>	...	<input type="checkbox"/>	...	<input type="checkbox"/>	.....	.....								
Andere lawaaierige vrije tijdsactiviteiten Specifieer:.....	<input type="checkbox"/>	<input type="checkbox"/>	...	<input type="checkbox"/>	...	<input type="checkbox"/>	...	<input type="checkbox"/>	.....	.....								
Lawaai op het werk Specifieer:.....	<input type="checkbox"/>	<input type="checkbox"/>	...	<input type="checkbox"/>	...	<input type="checkbox"/>	...	<input type="checkbox"/>	.....	.....								

20. Welke soort gehoorbescherming draagt u meestal?

- Kneedbare wegwerpdoppen (1)
- Universele oordoppen (2)
- Op maat gemaakte gehoorbescherming (3)
- Oorkappen (4)
- Geen



21. Beoordeel de volgende stellingen en kruis bij elke stelling 1 vakje aan.

	Volledig mee eens	Gedeeltelijk mee eens	Neutraal	Gedeeltelijk mee oneens	Volledig mee oneens
Ik vind het geluidsniveau in een discotheek, concert, of tijdens een ander evenement te luid.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Luisteren naar muziek tijdens het studeren of werken helpt me bij het concentreren.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Als ik moet studeren of werken maak ik mijn omgeving rustiger.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Ik overweeg een discotheek, concert, of ander evenement te verlaten wanneer het te luid is.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Ik kan me concentreren ook al zijn er verscheidene geluiden rond me.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Ik vind het niet nodig gehoorbescherming te gebruiken tijdens luide evenementen.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Ik vind het belangrijk mijn omgeving comfortabeler te maken qua geluidsniveau.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Ik vind het niet aangenaam wanneer het stil is rondom me.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
De geluidsniveaus in discotheken, concerten of andere evenementen zijn geen probleem.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Lawaai en andere luide geluiden maken deel uit van onze huidige maatschappij.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Lawaai veroorzaakt door het verkeer stoort mij niet.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
De geluidsniveaus in een discotheek, concert, of ander evenement moeten worden verminderd.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Ik vind dat een les- of werklokaal rustig en kalm moet zijn.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Geluiden van ventilatoren, koelkasten, computers,... storen mij niet.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Ik ben bereid activiteiten met luide geluidsniveaus op te geven.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Het geluidsniveau op mijn school of werk is comfortabel.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Ik vind het gemakkelijk verkeerslawaai te negeren.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Er zouden meer regels en wetgevingen moeten zijn voor geluidsniveaus in de maatschappij.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Wanneer ik mij niet kan verwijderen van storende geluiden word ik zenuwachtig.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Ik ondervind geen problemen om een gesprek te voeren in rumoerige en lawaaierige omstandigheden bv. op café.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

22. Beoordeel de volgende stellingen en kruis bij elke stelling 1 vakje aan.

	Volledig mee eens	Gedeeltelijk mee eens	Neutraal	Gedeeltelijk mee oneens	Volledig mee oneens
Ik denk dat gehoorbeschermers teveel druk op mijn oren zetten.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Ik geloof dat ik weet hoe ik gehoorbeschermers moet inbrengen en dragen.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Ik heb niet de intentie om gehoorbescherming te dragen wanneer ik in lawaaierige omstandigheden vertoef.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Ik geloof dat ik in een lawaaierige omgeving kan vertoeven zonder mijn gehoor te schaden.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Ik denk dat het dragen van gehoorbescherming elke keer ik in lawaai vertoef belangrijk is.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Ik draag gehoorbeschermers wanneer ik in lawaai ben.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Ik vind gehoorbescherming dragen oncomfortabel.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Mijn vrienden dragen nooit gehoorbescherming.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Ik weet niet zeker wanneer gehoorbeschermers aan vervanging toe zijn.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Mijn gehoor verliezen maakt het voor anderen moeilijk om met mij te praten.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Ik geloof dat mijn oren zich uiteindelijk aanpassen aan lawaai zodat er minder risico is op beschadiging.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Ik weet wanneer ik gehoorbeschermers zou moeten dragen.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Ik geloof dat blootstelling aan lawaai mijn gehoor kan schaden.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Ik ben ervan overtuigd dat ik gehoorverlies kan voorkomen wanneer ik in lawaaierige omstandigheden gehoorbeschermers draag.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Ik denk dat mijn gehoor geschaad wordt door blootstelling aan lawaai.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Gehoorbeschermers beperken mijn mogelijkheden om met anderen te communiceren.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Ik geloof niet dat een deel van mijn gehoor verliezen een grote handicap zou zijn.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Als ik gehoorbeschermers draag, bescherm ik mijn gehoor.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Gehoorbescherming dragen is vervelend.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Mijn vrienden vinden het een goed idee om gehoorbeschermers te dragen.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Ik denk niet dat het nodig is elke keer ik in lawaai vertoef gehoorbeschermers te dragen.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Ik denk dat dagelijkse blootstelling aan lawaai mijn gehoor uiteindelijk kan schaden.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Ik denk dat het een groot probleem zou zijn als ik mijn gehoor zou verliezen.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Ik ben van plan gehoorbescherming te dragen.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>



**Tot slot volgen nog enkele vragen met betrekking tot het voorkomen van oorsuizen (tinnitus) na lawaai blootstelling in de vrije tijd**

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23. Hoe vaak heeft u een volheidsgevoel na lawaai blootstelling tijdens activiteiten in uw vrije tijd? (vb.: het gevoel van een verkoudheid, het gevoel van proppen in de oren)

- Altijd
- Vaak
- Soms
- Zelden
- Nooit

24. Heeft u ooit tinnitus gehad na een vrijetijdsactiviteit?

(Hierbij kan het gaan om een piep, suis of andere geluid dat u waarnam na het bijwonen van een fuif, festival, concert, na het beluisteren van uw mp3-speler, bijwonen van een sportevenement, gebruik van luidruchtig gereedschap... en slechts enkele minuten, uren of dagen aanhield **of** om een geluid dat u nu nog steeds waarneemt)

- Ja (**Ga naar vraag 25**)
- Neen

Indien neen, dan stopt de vragenlijst hier voor u. Alvast heel erg bedankt voor uw medewerking!

Indien ja, ga naar **vraag 25**.

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25. Hoelang hield de tinnitus aan?

Indien u reeds meerdere malen tinnitus heeft gehad, gelieve de gemiddelde duur aan te duiden.

- < 30 minuten
- Tussen 30 minuten en 1 uur
- Tussen 1 en 3 uur
- Tussen 3 en 6 uur
- Tussen 6 en 12 uur
- Tussen 12 en 24 uur
- Tussen 24 en 48 uur
- Tussen 48 en 72 uur
- De tinnitus is nooit verdwenen (**Ga naar vraag 31**)

26. Hoe vaak heeft u tijdelijk tinnitus na recreatieve lawaai blootstelling (fuif, festival, concert,...)?

- Altijd
- Vaak
- Soms
- Zelden

27. Waar hoorde u de tinnitus?

- Rechter oor
- Linker oor
- Beide oren, meer rechts dan links
- Beide oren, meer links dan rechts
- Beide oren gelijk
- In het hoofd (geen duidelijke kant aan te geven)

28. Was de tinnitus eerder pulserend of continu?

- Pulserend (bv: synchroon met de hartslag, kloppend,...)
- Continu

29. Klonk de tinnitus meer als een toon of meer als een ruis?

- Toon
- Ruis (bv: ruisen van de wind, zee of bomen ,...)
- Combinatie van een toon en een ruis
- Andere: .....

30. Kan u de toonhoogte van uw tinnitus aangeven?

“Het begrip toonhoogte karakteriseert een geluid in termen van ‘hoog’ en ‘laag’. Wanneer een geluid hoog (scherp) klinkt dan gaat het om een geluid met een hoge toonhoogte, wanneer het laag (dof) klinkt is dit een geluid met een lage toonhoogte.”

- Hoge toonhoogte
- Gemiddelde toonhoogte
- Lage toonhoogte

Hier stopt de vragenlijst voor u.

Alvast heel erg bedankt voor uw medewerking!

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31. Kan u aangeven hoelang u reeds tinnitus hebt?

- < 1 maand
- Tussen 1 en 6 maand
- Tussen 6 maand en 1 jaar
- Tussen 1 en 5 jaar
- > 5 jaar

32. Waar hoort u de tinnitus?

- Rechter oor
- Linker oor
- Beide oren, meer rechts dan links
- Beide oren, meer links dan rechts
- Beide oren gelijk
- In het hoofd (geen duidelijke kant aan te geven)

33. Is de tinnitus eerder pulserend of continu?

- Pulserend (bv: synchroon met de hartslag, kloppend,...)
- Continu

34. Klinkt de tinnitus meer als een toon of meer als een ruis?

- Toon
- Ruis (bv: ruisen van de wind, zee of bomen ,...)
- Combinatie van een toon en een ruis
- Andere: .....

35. Beschrijf de toonhoogte van uw tinnitus.

“Het begrip toonhoogte karakteriseert een geluid in termen van ‘hoog’ en ‘laag’. Wanneer een geluid hoog klinkt dan gaat het om een geluid met een hoge toonhoogte, wanneer het laag klinkt is dit een geluid met een lage toonhoogte.”

- Hoge toonhoogte
- Gemiddelde toonhoogte
- Lage toonhoogte

36. Heeft u de indruk dat uw tinnitus luider is dan bij aanvang van het probleem?

- Ja
- Neen

## 37. Verandert de luidheid van uw tinnitus?

“Het begrip luidheid karakteriseert hoe sterk een geluid subjectief wordt ervaren”

- Ja  
 Neen (**Ga naar vraag 39**)

## 38. In welke situaties klinkt uw tinnitus luider? (Meerdere antwoorden zijn mogelijk)

- Wanneer ik angstig ben  
 Wanneer ik stress heb  
 Wanneer ik boos ben  
 Wanneer ik vermoeid ben  
 Wanneer ik alleen ben  
 Andere (specifieer) : .....

39. Beschrijf de luidheid van uw tinnitus op dit moment op onderstaande schaal.

“Het begrip luidheid karakteriseert hoe sterk een geluid subjectief wordt ervaren”

<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
1	2	3	4	5	6	7	8	9	10
Erg zacht			Matig				Erg Luid		

## 40. Indien u zich in een omgeving met lawaai bevindt (vb.: op straat, wanneer de radio op de achtergrond speelt, wanneer u met mensen in gesprek bent,...), merkt u een verschil in luidheid van uw tinnitus op?

- De tinnitus klinkt luider  
 De tinnitus klinkt even luid  
 De tinnitus klinkt zachter  
 De tinnitus verdwijnt

## 41. Beschrijf uw tinnitus in woorden:

De volgende lijst zijn voorbeelden van mogelijke sensaties, u bent vrij om ook andere beschrijvingen te gebruiken: sissend, rinkelend, pulserend, zoemend, klikkend, krakend, tonaal (zoals een beltoon of andere soorten tonen), hummend, ploppend, loeien van de wind, ruisend, typemachine, fluitend, suizend.

.....  
 .....  
 .....

42. Hoe vaak heeft u een probleem met verdragen van geluiden omdat ze vaak veel te luid lijken? Ofwel, vindt u dat geluiden te hard of te pijnlijk zijn die andere mensen om u heen niet onaangenaam vinden?

- Altijd  
 Vaak  
 Soms  
 Zelden  
 Nooit (*Ga naar vraag 44*)

43. Welke geluiden klinken onaangenaam voor u? (vb.: bestek, het klinken van glazen, papier verfrommelen,...)

.....

.....

.....

.....

44. Ten slotte willen we de invloed van tinnitus op uw leven nagaan. Hieronder vindt u 25 stellingen. Gelieve het meest correcte antwoord aan te kruisen.

		Ja	Neen	Soms
1	Kunt u zich door uw tinnitus moeilijk concentreren?	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
2	Kunt u door de luidheid van uw tinnitus anderen verstaan?	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
3	Bent u boos vanwege de tinnitus?	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
4	Voelt u zich verward door de tinnitus?	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
5	Voelt u zich wanhopig door uw tinnitus?	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
6	Klaagt u veel over uw tinnitus?	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
7	Kunt u door uw tinnitus 's avonds moeilijk in slaap vallen?	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
8	Heeft u het gevoel dat u niet aan uw tinnitus kunt ontsnappen?	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
9	Interfereert uw tinnitus met het deelnemen aan sociale activiteiten (uit eten gaan, naar de bioscoop)?	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
10	Voelt u zich door de tinnitus gefrustreerd?	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
11	Heeft u door uw tinnitus het gevoel dat u een vreselijke ziekte heeft?	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
12	Maakt de tinnitus u het moeilijk om van het leven te genieten?	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
13	Interfereert uw tinnitus met uw werk of huishoudelijke bezigheden?	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
14	Bent u door de tinnitus sneller geïrriteerd?	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
15	Heeft u door de tinnitus moeite met lezen?	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
16	Bent u overstuur door de tinnitus?	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
17	Heeft u het gevoel dat de tinnitus uw relaties met familieleden en vrienden onder druk zet?	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

---

18	Vindt u het moeilijk uw aandacht te verschuiven van de tinnitus naar andere zaken?	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
19	Heeft u het gevoel dat u geen controle heeft over uw tinnitus?	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
20	Bent u door de tinnitus vaak vermoeid?	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
21	Bent u door de tinnitus depressief?	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
22	Voelt u zich angstig en bezorgd door de tinnitus?	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
23	Heeft u het gevoel dat u niet langer met de tinnitus om kunt gaan?	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
24	Wordt de tinnitus erger in stressvolle situaties?	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
25	Voelt u zich onzeker door de tinnitus?	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

**Hartelijk bedankt voor uw medewerking!**

Drs. Sofie Degeest

o.l.v. Prof. Dr. P. Corthals en Dr. H. Keppler

## DANKWOORD

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Vijf jaar, drie maanden en drie weken geleden startte dit doctoraat, een avontuur dat ik kan omschrijven als een weg vol hindernissen maar ook vol hoogtepunten. Hindernissen kunnen overwonnen worden en hoogtepunten kunnen gevierd worden, hoewel dit niet mogelijk zou zijn zonder de steun en het vertrouwen van een aantal mensen. Nu ik aan het einde van mijn weg ben gekomen wil ik hen hiervoor dan ook heel graag bedanken.

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