Studies in Disability Research 119

Iris Elmazoska

Music and Hearing Health

- A study on music listening behaviors and hearing-related risks among young people

Author: Iris Elmazoska
Title: Music and Hearing Health - A study on music listening behaviors and hearing-related risks among young people

Publisher: Örebro University, 2025
www.oru.se/publikationer

Print: Örebro University, Repro 09/2025

ISSN: 2004-4887 (Print)
ISSN: 2004-4895 (Online)
ISBN: 978-91-7529-692-0 (Print)
ISBN: 978-91-7529-693-7 (Online)

Abstract

Concerns about noise-induced hearing loss among young people are increasing as young people frequently engage in music listening for extended periods of time and/or at high sound levels. The aim of this thesis was to investigate associations between music listening and hearing health among young people. Study I is a systematic review investigating associations between hearing function and recreational noise (focus on music exposure) among 10 – 30 year olds. Study II is a qualitative study exploring the meaning of music in the daily life of participant's (15 – 19 – year – olds) and how young people understand hearing-related risks. Study III is a cross-sectional study examining associations between measured headphone sound pressure levels (SPLs) with hearing thresholds and distortion product otoacoustic emissions (DPOAEs) among 10 – 20 year olds. Study IV is a cross-sectional study investigating how attitudes to noise/loud music and auditory symptoms (tinnitus, sound sensitivity etc.,) relate to hearing-and sound level measurements among 10 – 20 year olds. Study I showed that some previous research has found associations between music exposure with worse extended high-frequency (EHF) thresholds and reduced DPOAEs. However, consistent evidence of long-term effects remains limited, partly due to differing methods of exposure assessment across studies. Study II showed that music is an integral part of the participants' daily life and valuable for emotional regulation. Despite an awareness of the potential risks, the benefits of music outweighed any concerns about hearing health. Study III showed that older participants (age ≥15 years) had some slightly elevated EHF thresholds and reduced DPOAEs, but no statistically significant associations were found between measured SPLs and hearing outcomes. Study IV showed that more positive attitudes to noise/loud music were significantly associated with higher measured SPLs and longer daily listening durations (self-reported). Most auditory symptoms were not associated with hearing-or sound level measurements, except greater need for auditory recovery, which was associated with reduced DPOAEs. The overall results point to the importance of prevention efforts as potentially risky music listening behaviors may indicate early auditory changes related to noise exposure.

Keywords: Hearing health, Music listening, Headphones, High-frequency, DPOAE, Meaning-making, Auditory symptoms, Attitudes to Noise, Children, Adolescents

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List of Papers

This thesis is based on the following studies, referred to in the text by their Roman numerals.

I. Elmazoska, I., Mäki-Torkko, E., Granberg, S. & Widén, S. (2024). Associations Between Recreational Noise Exposure and Hearing Function in Adolescents and Young Adults: A Systematic Review. Journal of Speech, Language and Hearing Research, 67 (2), 688-710.

II. Elmazoska, I., Bengtsson, S. & Widén, S. (2025). *"It's about wanting to disappear from the world…"* – An Interpretative Phenomenological Analysis on the Meaning of Music and Hearing-Related Risks. International Journal of Qualitative Studies on Health and Well-being, 20(1).

III. Elmazoska, I., Persson Waye, K., Mäki-Torkko, E. & Widén, S. Headphone Listening Levels and Hearing Function Among Children and Adolescents. *Submitted for publication.*

IV. Elmazoska, I., Persson Waye, K., Mäki-Torkko, E. & Widén, S. Headphone Listening Levels, Attitudes to Noise and Auditory Symptoms Among Children and Adolescents. *Submitted for publication.*

Abbreviations

dB HL: Decibel Hearing Level

dB SPL: Decibel Sound Pressure Level

dBA: Decibel A-weighted

DeSO: Demographic Statistical Areas (Demografiska Statistik-områden)

DPOAE(s): Distortion Product Otoacoustic Emission(s)

EHF: Extended High Frequency

GDPR: General Data Protection Regulation

GRADE: Grading of Recommendations, Assessments, Development and Evaluation

HBM: Health Belief Model

HBQ: Hearing Beliefs Questionnaire

HHL: Hidden Hearing Loss

ICF: International Classification of Functioning, Disability and Health

IPA: Interpretative Phenomenological Analysis

ISO: International Organization for Standardization

LAeq: A-weighted Equivalent Continuous Sound Pressure Level

LEQ: Equivalent Continuous Sound Pressure Level

kHz: Kilohertz

NIHL: Noise-Induced Hearing Loss

NIOSH: The National Institute for Occupational Safety and Health

OAE(s): Otoacoustic Emission(s)

OHC: Outer Hair Cell

PCA: Principal Component Analysis

PLD: Personal Listening Device

PRISMA: Preferred Reporting Items for Systematic Revies and Meta-analyses

PTA: Pure-Tone-Average

PTS: Permanent Threshold Shift

SAF: Sound-induced Auditory Fatigue

SBU: Swedish Agency for Health Technology Assessment and Assessment of Social Services (Statens beredning för medicinsk och social utvärdering)

SCB: Statistics Sweden (Statistiska centralbyrån)

SNR: Signal-to-noise ratio

SPL: Sound Pressure Level

TEOAE(s): Transient-evoked otoacoustic emission(s)

TPB: Theory of Panned Behavior

TTS: Temporary Threshold Shift

WHO: World Health Organization

YANS: Youth Attitude to Noise Scale

Introduction and Rationale

Hearing loss is a growing public health concern, affecting nearly one in five people worldwide and contributing substantially to the global burden of disability [WHO, 2021; GBD 2019 Hearing Loss Collaborators, 2021]. Hearing loss is often considered an "invisible disability" due to the absence of visible symptoms and the stigma that can surround communication difficulties [Tang et al., 2023]. The negative consequences on communication ability can have other implications, such as poorer quality of life and poorer psychological and cognitive health [Gopinath et al., 2012; Gopinath et al., 2012; Jafari et al., 2019; Livingston et al., 2020]. Noise-Induced Hearing Loss (NIHL) is common. One of the most significant contributors to NIHL is recreational noise exposure. The World Health Organization [WHO, 2021] estimates that approximately 1.6 billion young people (12 – 35 years old) are at risk of hearing loss by 2050 due to unsafe recreational noise exposure. Unlike occupational noise, which is typically regulated, recreational noise often occurs in less controlled environments. These include live music events/concerts, nightclubs, and activities such as using personal listening devices (PLDs) and headphones, often at high sound levels and for extended periods of time.

Individuals with NIHL may experience tinnitus, sound sensitivity (hyperacusis), difficulty understanding speech in noisy environments and increased social withdrawal [Guo et al., 2024]. The potential consequences for children and adolescents are particularly concerning, as hearing loss at a young age can impede speech-and language development, educational attainment, and social and emotional wellbeing [Guo et al., 2024]. NIHL therefore represents an important target for public health interventions. Preventive strategies include promoting safe music listening behaviors, increasing awareness of noise-related risks, developing noise regulations, and increasing accessibility to hearing protection [Dillard et al., 2022; WHO & International Telecommunication Union, 2019].

The rationale for this work is founded on the growing prevalence of music listening and headphone use among children and adolescents/young adults. There is increasing concern regarding the risk of early development of NIHL based on risky music listening, which underlines the urgency of understanding the relationship between music exposure and hearing function. The WHO [2021] has highlighted the absence of globally implemented recreational noise regulations, signaling a pressing need for further research to explore determinants of unsafe music listening. In addition to measuring noise exposure and hearing health outcomes, it is also important to consider how young people relate to music in everyday life, how they use it, what it means to them, and how they perceive the potential risks. These dimensions are likely to influence risky music listening behaviors and may therefore be important to consider in developing relevant, youth-centered preventive strategies. Overall, additional research evidence on music listening behaviors is required as successful prevention relies on accurate and meaningful information regarding hearing health risks.

Background

Hearing and Noise

The auditory system consists of the outer ear, middle ear, inner ear, and central auditory pathways. Sound waves enter the ear canal, vibrate the tympanic membrane, and are transmitted via the ossicles to the cochlea. Inside the cochlea, vibrations are transformed into neural signals by hair cells and conveyed to the brain through the auditory nerve [Moore, 2012; Robles et al., 2001]. Sound is a form of mechanical energy transmitted through vibrations in air, liquid, or solid media. These vibrations are measured in terms of amplitude and frequency. Amplitude is expressed as sound pressure level in decibels (dB SPL), and frequency in hertz (Hz; number of cycles per second). The human ear can detect frequencies from approximately 20 Hz to 20,000 Hz, with the greatest sensitivity between 1,000 and 4,000 Hz [Gelfand, 2009].

In acoustics, noise is typically defined as a sound signal characterized by random fluctuations in a broad spectrum, with examples being white and pink noise [Everest, 2015]. From a communicative perspective, noise refers to any auditory stimulus that interferes with the perception or intelligibility of sounds, such as speech. In psychoacoustics, noise can be more broadly understood as “unwanted sound”, a subjective concept shaped by individual preferences, situational context, and cultural norms [Moore, 2012; Everest, 2015]. A sound perceived as pleasant by one individual, such as music, may be experienced as unpleasant by another. Importantly, in terms of health, even sounds that are intentional and wanted can be harmful to hearing if they are sufficiently intense or sustained over time [Reynolds & Bielefield, 2023].

Hearing Loss

Hearing loss can occur when any part of the auditory system is damaged [Gelfand, 2016]. It is typically categorized as conductive (affecting the outer or middle ear), sensorineural (affecting the inner ear or auditory nerve), or mixed. Sensorineural hearing loss, which includes

NIHL, is the most common form and in many cases is irreversible. It typically affects the higher frequencies first and may with continued exposure begin to affect lower frequencies as well [Gelfand, 2016].

Noise-Induced Hearing Loss

One of the mechanisms underlying NIHL is oxidative stress which damages the delicate structures in the inner ear [Kurabi et al., 2017]. This damage can lead to inflammation and eventually the death of hair cells. Exposure to loud noise can result in temporary threshold shifts (TTS) or permanent thresholds shifts (PTS). Hearing loss after a TTS has been considered reversible, often within 24 – 48 hours [Musiek et al., 2020]. However, this notion is increasingly being challenged by studies conducted on mice which have found that even when a TTS appears to fully reverse, it may still lead to nerve damage and accelerate the onset of age-related hearing loss [Hong et al., 2013; Gopal et al., 2019].

NIHL often lacks physical symptoms such as pain or audiometric changes in the early stages. Therefore, individuals with NIHL may not notice any hearing problems until it becomes difficult to understand speech [Le Prell et al., 2013]. Although the audiometric notch is generally well documented (e.g., NIHL typically begins with a sharp decline between 3 – 6 kHz), there is less information on the suprathreshold auditory processing deficits [Le Prell et al., 2013]. Preventive strategies are crucial in mitigating NIHL. These include the use of hearing protection, implementation of noise regulations, and public education on the risks of excessive noise exposure. Ongoing research also aims to develop pharmacological interventions targeting oxidative stress and inflammation pathways to prevent or reduce the impact of NIHL [Kurabi et al., 2017].

Hidden Hearing Loss

Hidden hearing loss (HHL) is a condition where individuals experience hearing problems, especially in noisy environments, but have no detectable hearing loss measurable through standard audiometry (125 – 8 000 Hz) [Liberman et al., 2016; Plack et al., 2014]. This challenges the traditional reliance on elevated (worse) hearing thresholds as the main indicators of hearing loss. Emerging research suggests that HHL may result from cochlear synaptopathy, e.g., damage to the synapses between the inner hair cells and auditory nerve fibers, often caused by noise exposure or aging [Liberman & Kujawa, 2017]. This damage may impair suprathreshold auditory processing without affecting hearing thresholds. Although direct observations of this condition in humans are limited, electrophysiological indicators such as altered summating potential/action potential ratios have shown promise as diagnostic markers [Liberman et al., 2016]. The research regarding HHL indicates that it is important to investigate beyond traditional hearing measurements to better identify early signs of hearing damage. Early identification may enable implementation of preventive efforts, potentially reducing the risk of further deterioration.

Recreational Noise

The term *recreational noise exposure* refers to exposure to noise during leisure time, as opposed to occupational noise exposure [Tordrup et al., 2022]. In this thesis, recreational noise exposure is broadly defined to include any noise exposure occurring outside of occupational activity. This involves exposure from sources such as movie theaters, gyms/sporting venues, concerts, nightclubs or other live music events, use of motor vehicles or power tools, recreational shooting/hunting, as well as use of PLDs and headphones to listen to music, podcasts, or other audiovisual content (e.g., TV/movies/social media/video games). Unlike occupational noise, recreational noise exposure is often voluntary and associated with enjoyable activities. Music, although not typically considered harmful, can reach sound pressure levels (SPLs) high enough to cause auditory damage, especially when listened to over extended durations of time [Portnuff et al., 2011].

The focus of the empirical studies (III and IV) in this thesis is on music listening with headphones. Previous research has indicated that loud music listening for extended periods of time may be associated with various hearing problems such as tinnitus, hyperacusis, and NIHL [Jiang et al., 2016; Vogel et al., 2011; le Clercq et al., 2016]. Several studies have identified adolescents and young adults as potentially vulnerable to the risk of developing NIHL as the use of PLDs and headphones has increased over the last two decades, leading to more risky music listening [Jiang et al., 2016; Feder et al., 2021; le Clercq et al., 2018; You et al., 2020]. According to a previous systematic review [Dillard et al., 2022] there was a high prevalence of PLD use at unsafe sound levels and a high attendance at venues and events where loud noise is present among 12 – 34 year olds. It was further projected that up to 1.1 billion young people worldwide could potentially be at risk of NIHL [Dillard et al., 2022]. Listening to music in headphones often starts at an early age with 28 % of 9-year-olds previously found to listen frequently, increasing to 88 % at 15 years old [Båsjö et al., 2016; Widén et al., 2017]. Despite an increasing prevalence of symptoms such as tinnitus or sound sensitivity due to loud music exposure [Berg et al., 2011; Jiang et al., 2016; Vasconcellos et al., 2014] as well as adolescents' self-reported awareness of the associated risks [Vogel et al., 2012; Gilles et al., 2012], the use of hearing protection remains low [Chung et al., 2005; Gilles et al., 2013].

Early indications of NIHL post music exposure have been observed in some studies. However, there is a lack of consensus on the extent of the risk and the relationship between exposure and hearing outcomes [Colon et al., 2016; Twardella et al., 2017]. Multiple studies have shown that individuals exposed to recreational noise on a regular basis experience symptoms such as tinnitus, hyperacusis, and difficulty understanding speech in noise or hearing loss [Chung et al, 2005; Derebery et al, 2012; Degeest et al, 2014; Gilles et al, 2012; Gilles et al, 2013; Keppler et al, 2015; McNeill et al, 2010; Muchnik et al, 2012; Muhr & Rosenhall, 2010; Silvestre et al, 2016; Sulaiman et al, 2013; Williams, 2005; Zocoli et al, 2009]. Sulaiman et al. [2013] reported that PLD users had significantly worse hearing thresholds at the extended high frequencies, as well as significantly reduced DPOAEs and transient-evoked otoacoustic emissions (TEOAEs). They also found that longer durations of PLD use correlated with worse thresholds. Similarly, previous research has identified decreased otoacoustic emissions (OAEs) in relation to PLD use [Sulaiman et al., 2014] and have shown that decreased OAEs may precede NIHL [Bhagat and Davis, 2008].

Conversely, some studies have not identified any risk of hearing loss from music listening/PLD use [e.g., Almeida et al., 2020; Grinn et al., 2017; Paping et al., 2022; Swierniak et al., 2020; Weichbold et al., 2012]. Amid these varying results, an important observation that several studies report is that many investigations lack adequate exposure assessments (e.g., measuring sound levels and/or hearing outcomes) [Kim et al., 2009; Schink et al., 2014]. Lack of exposure assessment is a serious weakness as the agreement between self-estimated and measured sound levels has been shown to be poor [Portnuff et al., 2013; Widén et al., 2018]. There is also large variation in reported music listening habits among adolescents between and within studies [Keppler et al., 2010]. This variation is seen in duration of use (years), listening time (hours per week) and listening levels (SPLs). Differences regarding PLD use may partly explain the inconsistencies between studies. For example, listening duration is sometimes measured as listening at a single data collection point [Keppler et al., 2014], and sometimes as listening over a full day, week, or month [Paping et al., 2021]. This increases the challenge of making direct comparisons between studies.

Previous studies on NIHL have emphasized the importance of performing not only conventional audiometry (0.25 – 8 kHz) but also EHF audiometry as elevated EHF thresholds may indicate early cochlear damage [Liberman et al., 2016; Prendergast et al., 2017]. In addition to EHF audiometry, measuring the function of the outer hair cells (OHCs) based on OAEs has been suggested for detection of early indications of NIHL. A previous study found that PLD use over a three-year period was associated with high-frequency hearing loss and reduced function of OHCs as indicated by OAEs [Biassoni et al., 2014]. Compared with non-users, PLD-users' hearing outcomes have shown indications of subtle damage to the OHCs, and elevated hearing thresholds measured through conventional audiometry [Aarhus et al., 2016; Vasconcellos et al., 2014]. Some studies have reported that DPOAEs may be particularly sensitive to early-stage NIHL [Narahari et al., 2017; Bal & Derinsu, 2021]. Therefore, it may be more likely that studies which use EHF audiometry and OAEs/DPOAEs detect early NIHL, especially in the case of cross-sectional studies.

Exposure Assessment and Guidelines for Safe Listening

Sound pressure levels are expressed in dB, with frequency-weighted filters applied to better match human auditory perception. The A-weighting filter (dBA) is the most commonly used in both occupational and environmental contexts, as it adjusts the measured sound levels to reflect the human ear sensitivity to different frequencies Neitzel & Fligor, 2019]. To assess noise exposure over time, the equivalent continuous sound pressure level (LEQ) is used. This value represents the average acoustic energy across a specified time interval. According to The National Institute for Occupational Safety and Health [NIOSH], in occupational settings, LEQ is typically calculated over 8 hours, whereas a 24-hour period is often used for environmental noise assessments. The LEQ calculation relies on the equal-energy principle, which means that exposure to the same total sound energy, regardless of its distribution, will result in a similar risk of hearing damage [NIOSH, 1998]. This principle is operationalized through a 3 dB exchange rate, where a 3 dB increase in sound level equates to a halving of the allowable exposure duration. For instance, 85 dBA over 8 hours is considered equally hazardous as 88 dBA over 4 hours or 91 dBA over 2 hours.

The WHO has emphasized the need for protective standards beyond occupational settings. In the *Environmental Noise Guidelines for the European Region* [WHO, 2019], the WHO introduced evidence-based recommendations for managing exposure to leisure noise. These guidelines recommend that noise exposure from all leisure sources should not exceed an average of 70 dB A-weighted equivalent continuous SPL (LAeq) measured over 24 hours. For short-term recreational exposure (such as concerts), the recommended limit is a maximum of 100 dB LAeq measured over 15 minutes. The WHO standard emphasizes that exposures exceeding these thresholds could increase the risk of permanent auditory damage.

Applying a standard guideline uniformly across different PLDs and headphones would be challenging; there is variability in the technical capabilities and acoustic properties of different PLDs and headphones [Portnuff et al., 2011]. Another challenging aspect is to ensure that users follow safe listening recommendations contrary to their personal preferences and due to low awareness of such recommendations [Chen et al., 2023]. The SPLs measured from PLDs, such as smartphones or iPods, have been shown to exceed 100 dBA [Portnuff et al., 2013]. Many adolescents and young adults use PLDs while studying, working, exercising, on public transportation, and/or sleeping [Li et al., 2019]. Therefore, there is a risk of excessive PLD use in daily life and in turn, increased hearing health risks. Kaplan-Neeman et al. [2017] and Paping et al. [2021] have previously shown the practicality of using smartphone apps to monitor daily listening habits. People often under-or overestimate their listening habits [Kaplan-Neeman et al., 2017]. Even a correct self-estimation does not necessarily mean the individual has awareness of the risk of developing NIHL. Determining the effects of output SPLs from different PLDs is a complicated task but necessary for regulatory purposes and prevention of NIHL. To clearly determine any link between PLD use and risk of hearing loss, and encourage safe listening habits in the general public, well-controlled studies are needed.

Music Listening Among Young People

In this thesis, the terms *children, adolescents*, and *young adults* are used to refer to individuals between the ages of 10 and 20 years old in the empirical studies (Studies II, III, and IV), and up to 30 years old in Study I. Although definitions vary, the WHO (2024) defines *adolescents* as those aged 10–19 years and *young people* as those aged 10–24 years. For consistency, the terms *adolescents* or *young people* will be used in most cases to describe the study population.

The concept of *music listening habits* in this thesis refers to the patterns and behaviors associated with how people engage in music listening. This concept is multifaceted, encompassing the frequency, duration, and context of music exposure, e.g., preferred sound levels and types of listening devices used. It also relates to hearing health and methods for measuring these aspects. Both the concepts of *music listening habits* and *music listening behaviors* have been used across all four studies in this thesis, each aiming to capture some specific aspects of how individuals engage with music. *Music listening habits* refers mainly to patterns that are often routine-based and embedded in daily life, such as having background music on while studying, commuting, cooking, or getting ready for the day. *Music listening behaviors* is used as a broader term that includes both habitual and intentional aspects of music listening, particularly in relation to discussions of risky music listening, such as prolonged or high-intensity headphone use. This distinction is based on theories where habits are considered to be automatic responses to contextual cues [Wood & Neal, 2007; Gardner, 2014], whereas behaviors can also encompass goal-directed and belief-driven actions [De Houwer, 2019]. Furthermore, *music listening behaviors* involve emotional and cognitive responses to music, as well as social factors and peer influence. This concept encompasses the role and meaning of music during adolescence and possibly beyond.

Although music has had a significant societal influence for decades, technological advancements have enhanced its accessibility and transformed the way people listen to it [Wang et al., 2020]. As previously mentioned, exposure to loud music over an extended period of time may be associated with adverse effects on hearing health, but also with lower quality of life [Warner-Czyz & Cain, 2016; Lee & Jeong, 2021; Herrera et al., 2016]. For instance, adolescents with acquired hearing problems often experience difficulties with communicating and performing in school, and experience lower self-confidence [Warner-Czyz & Cain, 2016, Herrera et al., 2016]. Questionnaire-based findings suggest that young people's attitudes toward loud music differ and depend on what they perceive to be normal as well as factors such as personality and symptoms of NIHL [Gilles et al., 2013; Landälv et al., 2013; Manchaiah et al., 2017].

Furthermore, previous studies have shown that individuals increase their preferred loudness of music as the background noise level increases, as well as when they are listening to their favorite songs [Portnuff et al., 2011; Danhauer et al., 2009]. It has previously been reported that different stages of development can be associated with increased risk-taking in teenagers due to changes in the reward system of the brain [Steinberg, 2008]. Some young people may prefer listening to loud music for such reasons. As they transition into adults and gain better cognitive control and emotional regulation, they also become better at resisting impulsive or risky behaviors [Steinberg, 2008]. As such, implementing hearing conservation strategies during these stages of development may be important for protecting young peoples' future hearing health [Jiang et al., 2016].

Adolescence is often marked by emotional and behavioral changes, and research has shown that music can play a crucial role in helping young people navigate these changes [Beckmann, 2013]. Studies show that adolescents often rely on music for various purposes, including managing their emotions, reducing stress, and improving social interactions [Beckmann, 2013; Groarke & Hogan, 2018; Schäfer et al., 2013; Miranda, 2012; Upadhyay et al., 2017]. The significance of music seems to extend beyond entertainment or esthetic enjoyment, often functioning as a tool for coping with the challenges of life and making interpersonal experiences more meaningful [Cross & Tolbert, 2016]. Music has been shown to have a strong influence on adolescents' worldviews, self-perception, and relationships, which underlines the role of music as an important aspect in health promotion [Beckmann, 2013]. Many adolescents are also in a developmental stage where peer influence is important [Vogel et al., 2010]. During this time, music can serve as a social avenue where young people connect with each other, share and express experiences or emotions, which in turn can play a role in shaping and strengthening their identities and relationships [Miranda, 2012].

Demographic Factors

Demographic factors have previously been shown to influence music listening behaviors. These factors include age, gender, parents' educational level and socioeconomic status [Vogel et al., 2007; Portnuff et al., 2016]. Studies indicate that men are more prone to engage in risky music listening compared with women [Torre, 2008; Dreher et al., 2018; Basu et al., 2019]. Men have also been found to use PLDs more often and to listen to music at higher sound levels compared with women [Widén et al., 2017]. These differences extend to perceptions of noise-related risks and the use of hearing protection, with women showing more caution regarding their hearing health [Widén et al., 2011]. Other risky behaviors such as smoking have been associated with higher levels of hearing-related risk behavior, with women tending to perceive these health risks as more serious than men do [Bohlin et al., 2011].

A lower level of education has been significantly associated with risky music listening among adolescents [Vogel et al., 2010; Dreher et al., 2018]. An association between socioeconomic status and young people's attitudes and behaviors regarding loud noise has previously been identified [Olsen-Widén & Erlandsson, 2004]. Adolescents who have parents with higher education levels are generally more aware of the risks of NIHL and are more likely to use hearing protection [Olsen-Widén & Erlandsson, 2004]. A longitudinal study in the US, following 8710 women with low socioeconomic status over a period of 24 years, showed an increase in NIHL from 10 % to 19 % in participants aged 12 – 20 years old at baseline [Berg et al., 2011]. The study population was characterized by increased exposure to PLDs, with reported use rising fourfold during the study period. In addition to increased PLD use, the authors discussed broader contextual factors, such as environmental exposure and less frequent use of hearing protection, which may have contributed to the observed increase in hearing loss.

Further, studies have shown that older adolescents tend to exhibit risky music listening habits to a greater extent than younger adolescents [Widén & Erlandsson, 2004, Vogel et al., 2007]. They also report a higher prevalence of auditory symptoms such as tinnitus and sound sensitivity, which may be related to longer cumulative exposure compared with younger adolescents [Widén & Erlandsson, 2004]. Previous research has reported differences between men and women regarding attitudes to noise and the use of hearing protection [Gilles et al., 2014; Zocoli et al., 2009; Widén et al., 2006]. Men might be more inclined toward risky music listening as they generally show more positive attitudes to noise compared with women, who more often report sound sensitivity (hyperacusis), which in turn is associated with increased use of hearing protection [Vogel et al., 2008; Zocoli et al., 2009].

Furthermore, in a cross-cultural study investigating attitudes to noise, it was reported that American students had more pro-noise attitudes and were less likely to use hearing protection compared with their Swedish students [Widén et al., 2006]. These aspects need to be further investigated but suggest that it may be important to consider the effects of moderating or confounding variables such as gender, age, culture, and socioeconomic background. Identifying determinants of unsafe listening habits may also help to further define target groups for prevention.

Prevention of NIHL

Accumulating knowledge of how young people perceive risks associated with high sound levels may offer valuable insights into the factors that influence risky music listening behaviors, which in turn could aid creation of more relevant preventive strategies. Research has shown that educational campaigns and information-based strategies alone often fail to achieve sustained behavior change [Gilles & Paul, 2014; Weichbold & Zorowka, 2007]. Some educational programs have been successful in raising awareness and improving attitudes toward safe listening but translating this into behaviors such as increased use of hearing protection over time remains challenging [Griest et al., 2007; Martin et al., 2013]. Preventive efforts that fail to address motivational barriers and connect on a personal level often have limited success [Portnuff et al., 2013].

On the other hand, peer-based and community-based education models have been more successful among adolescents. A study by McCullagh et al. [2020] found significant improvements in participants' knowledge and attitudes, as well as lasting behavior change, from a combination of peer support and internet-based learning. Similarly, Keppler et al. [2015] investigated education programs which incorporated hearing assessments and found that personalized advice from audiologists heightened awareness and encouraged more consistent adoption of protective behaviors. The enjoyment derived from music listening is often associated with high sound levels [Zhu et al., 2022]. For example, Mercier and Hohmann [2002] found that some young people believe that loud music enhances the overall experience of music listening. Studies have shown there is a general reluctance to use hearing protection even in case of awareness of the risks associated with loud music [Bogoch et al., 2005; Olsen-Widén & Erlandsson, 2004]. Given that the risk of NIHL can result from multiple noise sources [Neitzel & Fligor, 2019], it may be effective to prioritize reducing exposure from sources that are more modifiable, such as personal music listening, while recognizing that behavioral factors can complicate this. To guide such preventive efforts, there is a need for more studies that measure and evaluate factors influencing the relationship between exposure and hearing outcomes. A better understanding of how risky music listening behaviors develop requires an approach that considers not only the potential hearing health risks, but also the meaningful and positive roles that music plays in young people's lives [Beckmann, 2013].

Theoretical Framework

The theoretical framework for understanding factors contributing to shaping risky music listening behavior is mainly based on the Health Belief Model (HBM) [Rosenstock, 1974] and the Theory of Planned Behavior (TPB) [Ajzen, 1991], alongside additional insights relating to disability research. The HBM and TPB have been widely used to understand health-related behaviors. The HBM focuses on health-related perceptions and barriers to protective behaviors, whereas the TPB describes social and psychological predictors of intention and behavior. Together, they allow for exploration of factors such as attitudes, susceptibility, severity, intention, and subjective norms in relation to decision-making, as well as of how contextual factors such as barriers and cues to action, may shape the adoption of safe listening behaviors.

The Health Belief Model

The HBM takes six factors into consideration: perceived susceptibility, perceived severity, perceived benefits, perceived barriers, self-efficacy, and cues to action [Rosenstock et al., 1988]. Perceived susceptibility refers to an individual's perception of being vulnerable to poor health, illness or injuries, whereas perceived severity refers to the individual's perception of the consequences that poor health would have in life. Perceived benefits refers to the individual's perception of the potential advantages of changing a risk behavior, whereas the concept of perceived barriers encompasses the individual's perception of obstacles to adopting a more health-oriented behavior. Self-efficacy refers to how capable an individual feels of performing a behavior that supports their health, such as using hearing protection or lowering the sound level when listening to music.

In addition to these factors, cues to action, which function as triggers of health-oriented action, may be necessary for an individual to change a risk behavior. Such cues to action can be the experience of negative consequences of the specific risk behaviors. In this case it could be symptoms of NIHL such as tinnitus or sound sensitivity, after exposure to loud noise. An individual's overall belief in the effectiveness of behavior change will encompass consideration of whether the benefits outweigh the cost of implementing it [Rosenstock, 1974]. A previous meta-analysis has shown that perceived benefits, cues to action, and perceived barriers were strong predictors of health-oriented behavior [Carpenter, 2010]. Similarly, a previous study has shown that cues to action and barriers are important for explaining the variation in the use of hearing protection [Widén et al., 2013].

The Theory of Planned Behavior

According to the TPB, a health behavior is the direct result of behavioral intention. Behavioral intentions are in turn made up of three components: attitudes toward a behavior, subjective norms regarding the behavior/action, and perceived behavioral control. Attitudes refer to whether an individual views a behavior as positive or negative. This is shaped by beliefs about the likely outcomes of the behavior and how the individual assesses those outcomes (e.g., beneficial vs. harmful, enjoyable vs. unpleasant). Subjective norms reflect perceived social pressure to perform or not perform a behavior/action. They are based on the individual's beliefs about what others (e.g., friends, family, peers) think they should do (normative beliefs), along with their motives to conform with those expectations. In the context of music listening, an individual may be more likely to lower their preferred listening level if they believe their peers value safe music listening, and if they care about aligning with those expectations. Perceived behavioral control is the perception that one can perform an action and that it will have the intended effect.

There are some previous studies that investigate TPB factors and the use of hearing protection [Quick et al., 2008; Gilles et al., 2014; Widén et al., 2013]. However, there are, to our knowledge, no studies on the TPB in relation to children's and adolescents' music listening and measured sound levels. Based on the TPB, it could be hypothesized that attitudes to noise and loud music, subjective norms regarding preferred sound levels, and perceived behavioral control may be associated with the intention to lower or raise sound levels and use or not use hearing protective devices in various situations and environments.

According to the HBM, individuals with low perceived susceptibility may not recognize their habitual music listening as risky, leading to passive exposure. However, when individuals experience cues to action (for example tinnitus), they may re-evaluate their perceived risk and adjust their listening behaviors accordingly. In contrast, the TPB helps explain how adolescents who actively expose themselves to risk by increasing sound levels or ignoring safety recommendations often demonstrate high behavioral intention but low self-regulation, especially when social norms favor risky listening. This theoretical framework sheds light on the complexity of music listening behaviors, and the need for interventions that address both habitual exposure and risk-taking.

Hearing Health and Disability Research

In clinical audiology, "normal" hearing sensitivity for adults (≥ 18 years old) is commonly defined as pure-tone thresholds between 0 and 25 dB HL across 125 – 8000 Hz [Katz, 2015]. However, this definition can be examined for its limited scope in capturing the complexities of auditory function and its impact on individuals' daily life. Research indicates that individuals with "normal" hearing thresholds can nonetheless experience significant hearing problems, particularly in challenging sound environments [Liberman et al., 2016]. Thus, in preventive audiology, relying on audiometric definitions of hearing sensitivity may lead to underestimating the need for early preventive efforts. Individuals with self-reported hearing problems may still benefit from counseling, hearing conservation strategies, or assistive listening devices to prevent further auditory deterioration [Tremblay et al., 2015].

Furthermore, previous studies have explored the relationships between the development and impact of NIHL on quality of life [Natarajan et al., 2023; Seidman & Standring, 2010]. The consequences of hearing loss include social, economic, cultural, and personal domains [Dalton et al., 2003], highlighting the need for a comprehensive strategy to address all these aspects. Hearing health is an integral part of overall well-being, aligning with the WHO's definition: "health as a state of complete physical, mental, and social well-being and not merely the absence of disease or infirmity" [WHO, 1948, p.100].

The International Classification of Functioning, Disability and Health (ICF) [WHO, 2001] provides a comprehensive framework for understanding experiences, moving beyond the concept of impairment alone. In the ICF model, impairment refers to physiological problems, such as cochlear damage. Activity limitations denote the problems people may have in performing certain tasks, such as following conversations in noisy settings, whereas participation restrictions involve difficulties in engaging in daily life situations, for example communication difficulties leading to avoidance of social situations. Disability, according to the ICF, is not solely a result of impairment but arises from the interaction between impairment and contextual factors, including environmental and personal factors, which in turn may lead to activity limitations and participation restrictions.

To further contextualize hearing health within this framework, the Brief ICF Core set for Hearing Loss [Danermark et al., 2013] offers a targeted application of the ICF for audiological purposes. It identifies relevant ICF categories related to hearing, communication, functioning, and participation, helping to capture the everyday impact of hearing problems even among individuals who fall within the "normal" hearing thresholds [Danermark et al., 2013]. Incorporating these frameworks into both research and practice supports more person-centered approaches by acknowledging that even early auditory symptoms can affect functioning and participation. This perspective sheds light on the value of including self-reported hearing problems, personal experiences, and contextual influences in audiological assessments [Tremblay et al., 2015; Meyer et al., 2016]. It also emphasizes that prevention of impairments and associated health problems is a key component in promoting functioning, particularly when considering fluctuating or early-stage hearing problems in youth.

Summary of Background

Hearing is a complex process essential for communication, learning and social interaction. Sound enables these functions, but excessive noise, whether from occupational, environmental or recreational sources, can be harmful to hearing health. Music, although generally subjectively perceived as pleasant, can pose risks when listened to at high sound levels or for extended durations of time. NIHL often develops gradually, meaning that it can go unnoticed. This has led to growing attention to the concept of HHL and the limitations of different definitions of "normal" hearing thresholds in assessment of hearing health. Children and adolescents are often considered a particularly vulnerable group due to exhibiting risky music listening behaviors. Despite awareness of potential hearing-related risks, preventive behaviors, such as using hearing protection, remain uncommon among young people.

Factors such as age, gender, and socioeconomic background may contribute to shaping preferences and attitudes toward noise. Theoretical perspectives can help explain how attitudes, perceived risk, and social norms influence hearing-related behaviors. Additionally, frameworks like the ICF emphasize the need to consider subjective symptoms and environmental context in hearing health. From this perspective, prevention of NIHL is associated with decreased levels of disability and promotion of overall functioning. Early identification and intervention can therefore help reduce the impact of auditory symptoms in daily life and facilitate active communication and participation. Existing studies on recreational noise and music listening show varying results, largely due to methodological differences and limited use of hearing-and sound level measurements. Nevertheless, there is consistent evidence that exposure to high sound levels can lead to auditory symptoms, worse hearing thresholds, and early signs of cochlear damage. Music is not always seen as a source of potential harm; it is frequently used for emotional regulation, stress relief, and identity formation. It accompanies daily routines and provides comfort, motivation, and a sense of belonging. These aspects can be particularly important during adolescence. Understanding both risks and the role of music as a contributor to well-being is central to the development of effective preventive strategies that promote hearing health without diminishing the positive effects of music in young people's lives.

Research Aim

The overall aim of this thesis is to investigate associations between music listening and hearing health among children and adolescents/young adults. By combining hearing-and sound level measurements with self-reported data and qualitative insights, the project explores headphone music listening in relation to hearing function, how young people understand the role of music and associated risks, as well as their attitudes to noise and loud music. This approach aims to provide a broader understanding of the factors that may contribute to potentially risky music listening behaviors. It also aims to improve knowledge of hearing problems related to recreational noise among young people, which may support future development of research or effective prevention strategies.

The specific aims for the four studies were:

Study I: To synthesize research evidence on associations between recreation noise exposure and hearing function, with PLD use/headphone music listening as the primary exposure.

Study II: To explore adolescents' perspectives on the meaning of music in their life, and how they understand the hearing-related risks associated with music listening.

Study III: To investigate associations between measured sound levels (using participants' headphones) and hearing measurements, and to compare participants' estimated daily noise doses with noise regulations.

Study IV: To explore associations between attitudes to noise and measured SPLs/noise dose, as well as associations between self-reported auditory symptoms and hearing-and SPL measurements/noise dose.

Materials and Methods

This research project used a mixed methods approach to investigate music listening habits and hearing health. The data were collected at the Audiological Research Center in Örebro, Sweden. Details on the methods of each study can be found in Studies I-IV. Table 1 below shows an overview of the study designs.

Table 1. Overview of the four studies in this thesis.

Study	**I**	**II**	**III**	**IV**
Study design	Systematic review	Interview study	Cross-sectional study	Cross-sectional study
Study population	Previous studies on hearing function and music listening among 10 – 30 year olds	Avid music listeners, four girls and three boys, age 15 – 19 years	Children and adolescents/young adults (n = 53), age 11 – 20 years, female: n = 33 and male: n = 20	Children and adolescents/young adults (n = 71), age 10–20 years, female: n = 41 and male: n = 30
Data collection method	Electronic database search	Individual semi-structured interviews	Questionnaire, hearing measurements, and sound level measurements	Questionnaire, hearing measurements, and sound level measurements
Outcome measures	Hearing function (descriptive synthesis of associations between exposure and outcome)	Thematic findings (interpretative phenomenological analysis)	Hearing thresholds and DPOAE amplitudes (linear regression)	Measured headphone SPLs and hearing-related symptoms (linear regression)

Study I

Study I was a systematic literature review, including peer-reviewed original studies on the associations between hearing function and recreational noise exposure, with a focus on music listening with headphones/PLD use. The review encompassed a detailed search across five databases for studies published between the years 2000 and 2023. The review protocol was registered with the International Prospective Register of Systematic Reviews (PROSPERO) (ID no:

CRD42021240040), in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-analyses (PRISMA) guidelines [Page et al., 2020]. The risk of bias assessment was conducted with the use of checklists provided in the handbook of the Swedish Agency for Health Technology Assessment and Assessment of Social Services (SBU) [2020]. The SBU refers to the Cochrane Handbook for Systematic Reviews of Interventions [Higgins et al., 2019] for the equivalent methodology in English.

Data extraction was based on both the SBU handbook and the PRISMA guidelines [SBU 2020; Page et al., 2020], with the approach for systematic literature synthesis following the steps outlined by Coughlan and Cronin [2021]. This method involved a detailed examination of the findings to understand the primary outcomes, summarize the findings in relation to the research question, and integrate the extracted data into a textual narrative. The aim of this method is to elucidate the findings of individual studies, identify connections between them, and derive a new understanding based on the synthesis [Coughlan & Cronin, 2021]. The reporting of results adhered to the method described by Coughlan and Cronin [2021], and the quality of evidence was collectively evaluated using the Grading of Recommendations, Assessment, Development, and Evaluation (GRADE) framework [SBU, 2020; Murad et al., 2017].

Study II

Study II utilized a qualitative approach to gain insights into adolescents' motivations for listening to music from their own perspectives. Semi-structured interviews were conducted, and the material was analyzed using interpretative phenomenological analysis (IPA). IPA is grounded in phenomenological principles that emphasize understanding individuals' subjective experiences and the meanings they assign to those experiences [Smith et al., 2022]. The goal was to capture the phenomenon from the participants' viewpoints, focusing on detailed case study analysis rather than broad generalizations. This approach is particularly effective for exploring shared experiences within a relatively similar group, such as motivations for music listening among adolescents. Through this method, the significance of music in young people's lives was explored, with the goal of providing a thorough examination of both individual and general experiences within the studied group.

Seven adolescents participated in this study, recruited through information letters distributed at three upper secondary schools and at Örebro Kulturskola in Örebro, Sweden, using purposive sampling. The participant age range was 15 – 19 years and they were selected based on their potential to provide information relevant to the aim of the study. Daily or highly frequent music listening experiences were required. Exclusion criteria were having diagnosed hearing loss, as those people's engagement with music listening might differ from that of people without hearing loss (and to align with the inclusion criteria of the other studies in the project). However, self-reported symptoms such as tinnitus or sound sensitivity were accepted.

The seven interviews were tape-recorded, transcribed verbatim, and analyzed in accordance with the IPA method [Smith et al., 2009; Smith et al., 2022]. The interview process was designed to produce detailed descriptions of the adolescents' experiences with music, with an interview guide created using open-ended questions supplemented by potential "prompts" for deeper exploration. The interviews varied in length and structure, tailored to the flow of conversation, but all topics were covered with each participant. The analytical process began with identification of emerging themes within each individual interview, where meaning units (experiential statements) were grouped into initial themes. These initial themes were then analyzed across participants to explore shared superordinate themes. The themes were discussed throughout the analytical process between all co-authors in the group. This helped ensure that the interpretations were plausible and grounded in the data.

The findings presented in Study II are the superordinate themes, supported by participant quotes and corresponding interpretations, to describe the central experiences regarding the research subject. The results and discussion section in this thesis contains a more detailed description of the analytical process in Study II, using examples from the findings.

Studies III and IV

The description for the data collection process is the same for Studies III and IV as they were based on the same study sample. Their aims and analyses differed.

Inclusion Criteria

Eligible study participants were individuals between the ages of 10 and 20 years, with hearing thresholds ≤ 25 dB pure-tone average of 500, 1000, 2000, 4000 Hz) (PTA) in both ears at baseline. This threshold was chosen in order to allow for longitudinal follow-up analyses as the original study design aimed to monitor changes in hearing function over time. Self-reported symptoms such as tinnitus or sound sensitivity were accepted.

Recruitment

Participants were recruited using a convenience sampling strategy, targeting 10 – 20 year olds. Recruitment efforts began in October 2021, and continued until August 2024, primarily through communication with schools in Örebro, Sweden. Participants were informed about the study either through information leaflets distributed at the schools or via the Swedish national healthcare platform 1177.se, which provides health-related information and services. Data collection, described in detail below, took place at the Audiological Research Centre in Örebro, Sweden. Of the 71 individuals who responded to the questionnaire, 53 also participated in the hearing-and sound level measurements.

Measurements

Hearing Measurements and DPOAEs

Hearing thresholds were assessed using pure-tone audiometry as described by the International Organization for Standardization [ISO, 8253-1:2010]. Mean hearing thresholds (PTA) were calculated at 0.5, 1, 2, and 4 kHz. Prior to conducting the hearing measurements, otoscopic examination was conducted as well as tympanometry using the

Titan system (Interacoustics A/S, Middelfart, Denmark) with a 226 Hz probe tone to confirm unobstructed ear canals and normal middle ear function. Pure-tone audiometry was performed by licensed audiologists in a soundproof booth using a Madsen Astera² clinical audiometer (Otometrics/Natus Medical Inc, Taastrup, Denmark) and TDH 39 headphones for frequencies 125 – 8000 Hz, whereas Sennheiser HDA 200 headphones were used for frequencies 9 – 16 kHz. The criteria for inclusion were set to have a hearing threshold of PTA ≤ 25 dB HL. A discussion on the justification for this criterion can be found in the results and discussion section.

DPOAEs were recorded with a DP Echoport 292 device and ILOv6 software from Otodynamics Ltd (Hatfield, United Kingdom). The DPOAEs were elicited with primary tones f_1 and f_2 at 65 dB SPL and 55 dB SPL, respectively, with a fixed ratio of 1.22 between them. The frequency resolution included 4 points per octave, which resulted in the following test frequencies: 842 Hz, 1001 Hz, 1184 Hz, 1416 Hz, 1685 Hz, 2002 Hz, 2380 Hz, 2832 Hz, 3369 Hz, 4004 Hz, 4761 Hz, 5652 Hz, 6726 Hz, 7996 Hz and 9509 Hz. The measurement window was set to 90 seconds per ear using an "intelligent sweep" strategy. DPOAEs were considered present when response amplitudes exceeded 0 dB SPL, and the signal-to-noise ratio was greater than 6 dB SPL.

Sound Level Measurements

The sound level measurements were performed using a KEMAR type 45BM manikin (G.R.A.S Sound & Vibration, Denmark). The setup included a half-inch pressure field microphone (GRAS 40AG) conforming to IEC 61094-4 standards and an ear simulator (GRAS RA0045) compliant with IEC 60318-4 (previously IEC 711). Anthropometric pinnae (GRAS KB5000 and KB5001) were fitted on the manikin to simulate the human ear's acoustic properties. The measurements were taken using a Brüel & Kjær PULSE Labshop, version 18, running on a Windows 10 computer, using 3560 front-end hardware with four input channels.

Measurements were conducted in both quiet and noisy test conditions as this is vital for correct exposure classification and because the preferred listening levels tend to increase by about 8 – 9 dB SPL with higher background noise levels [Portnuff et al., 2011]. The participants were asked to bring their PLDs (which were usually smartphones), and their own headphones. In cases where participants' forgot to bring their own headphones, we provided supra-aural AKG K-141 headphones, and music playback was done via our computer. The participants were asked to choose a preferred song and the typical listening level they would tend to use in a quiet setting. The headphones were then placed on manikin's ears. The music started and after 10 seconds, a 120-second sampling time started measuring LAeq over 120 seconds and max and peak levels in 1/3 octave bands from 20 Hz to 20 kHz (according to IEC 1260).

The procedure was then repeated with the same song but with the added instruction to the participant to choose their preferred listening level while simulated traffic noise at 66 dBA played in the background through surrounding speakers. Data were recalculated to A-weighted equivalent continuous sound levels, corrected for diffuse field (as described in ISO-11904-2), to enable comparison with WHO guidelines for safe listening. All measurements were recorded in a semi-anechoic chamber where the ambient noise was measured, to ensure acceptable levels (< 35 – 40 dBA).

In the KEMAR manikin, the following measurements were recorded for each participant:

<u>Equivalent continuous sound level over 2 minutes, A-weighted (LAeq measured over 2 minutes):</u> Reported LAeq values were based on measurements conducted over a continuous 2-minute period for each individual per measurement. These values represent the average SPL that the participant was exposed to over this period.

<u>Maximum sound level (Lmax, A-weighted):</u> This value indicates the highest sound level observed during each 2-minute measurement period.

<u>Peak sound pressure level (Lpeak, A-weighted):</u> The peak value refers to the highest instantaneous SPL during a measurement period.

The measured LAeq levels are presented for both test conditions, quiet and noisy. These values represent the SPLs that participants would be exposed to, without adjustments for listening duration or normalization to recommended safe limits.

Noise Dose Estimations

To compare participants' noise exposure against the WHO Environmental Noise Guidelines for the European Region [2019], noise doses were estimated using a 24-hour reference period, and 70 dBA as reference sound level (70 dB LAeq measured over 24 hours). This threshold is intended to minimize the risk of auditory damage. The estimations presented in Studies III and IV follow the ISO 1999:2013 standard for assessing equivalent noise exposure which was adapted to reflect the 24-hour reference period. The formula used was:

$$L_{ex,24h} = L_{PAeq,Te} + 10log_{10}\left(\frac{T_e}{T_0}\right)$$

$L_{ex,24h}$: normalized equivalent continuous sound level over 24 hours

$L_{PAeq,Te}$: measured A-weighted equivalent continuous sound level (output SPLs) over the exposure duration, T_e.

T_e: exposure duration in hours (self-reported listening duration, hours/day).

T_0: reference duration (24 hours).

Test Protocol

Each session of data collection lasted for 80 – 100 minutes per participant. The test protocol was followed in the order of the steps outlined below for all participants, with the exception of 11 individuals who completed the questionnaire first due to remote data collection during the COVID-19 pandemic. Participants were instructed to refrain from music listening in headphones during the 24 hours prior to the appointment, in order to minimize the potential influence of temporary auditory fatigue on the test results.

1. Introduction (≈ 5 minutes)
2. Otoscopy and tympanometry (≈ 5 minutes)
3. DPOAEs (≈ 5 minutes)
4. Pure-tone audiometry 125 – 8000 Hz (air and bone conduction) (≈ 20 minutes)
5. Extended high frequency audiometry (9 – 16 kHz) (≈ 10 minutes)
6. Sound level measurements (≈ 15 minutes)
7. Questionnaire (15 – 20 minutes)

The sessions began with a brief introduction during which participant information was reviewed, and previously obtained written consent was confirmed verbally. Participants also responded to a few questions about any recent exposure to loud noise and music listening/headphone use, as well as any known or perceived hearing problems in general. Then followed otoscopy and tympanometry to control for any factors that might interfere with further testing (e.g., cerumen, infection, or pressure imbalance). We were able to manage cerumen removal on site when necessary. DPOAEs followed, which required no active participation, before moving on to the pure-tone audiometry and EHF audiometry which required more attention and response consistency. After the hearing measurements, participants had a resting break of 10 – 15 minutes before participating in the sound level measurements. The participants then had their headphone sound levels measured, once in a quiet test condition and once in a noisy test condition (with simulated traffic noise at 66 dBA). Last of all, the questionnaire was completed (web-based), except for 11 participants who completed the questionnaire first (remotely, during the Covid-19 pandemic).

Questionnaire

The participants completed a questionnaire designed to assess their music listening habits and self-reported hearing health. The questionnaire included the Hearing Beliefs Questionnaire (HBQ) [Saunders et al., 2013], a 26-item measure of HBM constructs. The HBQ has demonstrated acceptable reliability, with Cronbach's α values ranging from .61 to .82. Participants' attitudes toward noise were measured using the Youth Attitude to Noise Scale (YANS), originally developed in a doctoral thesis [Widén, 2006]. In Study IV, a revised version of the scale (YANS-R) was used [Widén et al., 2013]. The revised version comprises 11 items out of the original 19 and has demonstrated good internal consistency (Cronbach's $\alpha = .83$). To tailor the scale to the aim of this thesis, two additional items addressing music listening with headphones were added (see items 12 and 13 in Table 2).

To examine the underlying structure of the attitudes to noise scale, a Principal Component Analysis (PCA) with Oblimin rotation was performed (see Table 3 below). The Kaiser-Meyer-Olkin (KMO) measure was .812 and Bartlett's test for sphericity showed significance ($p < .001$). The analysis showed some dimensional variation, but the overall pattern of loadings and the high internal consistency of the scale ($\alpha = .87$) provided support the 13 items to be included in a composite index. Three components were extracted which accounted for around 65 % of the total variance. Component one corresponds to positive attitudes toward loud music and high sound levels in leisure contexts. Component two represents positive attitudes toward environmental noise and more negative attitudes toward hearing protection. Component three reflects more protective attitudes in relation to noise.

Intercorrelations between the components were assessed (see Table 4 below). A significant moderate correlation was found between component one and component two ($r = .324$, $p = .030$), indicating some shared variance. No significant correlations were observed between component three and the other two components, suggesting that protective attitudes are relatively distinct from general enjoyment and tolerance of loudness.

All 13 items were rated on a five-point Likert scale ranging from 1 ("Disagree completely") to 5 ("Agree completely"), with an additional option (6 = "Cannot answer") available. Responses marked as "Cannot answer" were treated as missing data, though the proportion of such responses was low and did not substantially affect the dataset (see the methods discussion in Study IV for further elaboration on the "Cannot answer" responses). First, five negatively phrased items (see Table 2) were reverse-scored to ensure that higher scores consistently reflected more positive attitudes. A summary index was created by computing the mean score across all items. This index variable was used in subsequent statistical analyses in Study IV.

Table 2. Attitudes to noise (index).

YANS items	Items added	Cronbach's α
1. Music is best when the sound level is very high	12. When I listen with headphones (to music, games, audiobooks etc.), I like to listen at a high sound level	Prior to adding items 12 and 13: α = .831
2. The sound level at cinemas, concerts, and entertainment venues are not a problem for me.	13. The music experience in headphones is best when the sound level is high	After adding items 12 and 13: α = .877
3. It is necessary to use hearing protection at concerts*		
4. I am willing to leave if the noise level is too high*		
5. It is easy for me to disregard high noise levels		
6. There should be laws regulating (deciding on) noise levels in app public places where music is played*		
7. High sound levels are a natural part of our society		
8. I believe that music at discos and concerts should be played so loud that it can be felt in the body		
9. I think the sound level at clubs would feel better if it were lower*		
10. High sound levels are not a problem for me if it is music that I enjoy		
11. I believe that noise levels in society in general are too high		

*Reverse-scored items.

Table 3. Pattern matrix from Principal Component Analysis with Oblimin Rotation.

Item no.	Component 1	Component 2	Component 3	Communalities	Total	Corrected item-total correlation
1	.890			.816		.718
13	.877			.836		.769
12	.842			.788		.753
8	.747			.701		.675
7	.737			.483		.546
10	.620			.595		.626
9	.481			.367		.329
2		.817		.662		.295
11		.740		.689		.138
5		.687		.715		.406
3		.629		.588		.347
4			.880	.774		.339
6			.510	.484		.319
Eigenvalue	5.539	1.710	1.249			
Explained variance (%)	42.609	13.152	9.609		65.370	
KMO					.812	
Cronbach's α	.887	.752	.704		.877	

Note. Extraction method: Principal component analysis. Rotation method: Oblimin with Kaiser normalization. Loadings below .30 suppressed and loadings below .35 not presented.

Auditory symptoms were assessed through questionnaire items using either yes/no responses or Likert scales. The symptoms included in the analyses were tinnitus, sound sensitivity (hyperacusis), need for auditory recovery (rest), attenuated auditory sensation (following loud noise exposure), and sound-induced auditory fatigue (SAF) [Fredriksson et al., 2019]. Item formulations and response formats can be found in Study IV.

Statistical Analysis

The data were analyzed using the Statistical Package for the Social Sciences, software version 24.0.0.0 (BM SPSS, Inc., Chicago IL, United States). All statistical tests were conducted using α level .05.

Descriptive statistics were used to present participant characteristics as well as outcomes for hearing health and music listening habits (Studies III and IV).

Spearman's rank correlation was used to explore whether higher headphone listening levels were related to higher (worse) hearing thresholds or reduced DPOAE amplitudes (Study III), and whether more positive attitudes to noise were related to higher listening levels (Study IV).

Mann-Whitney U tests were used to assess differences between groups (e.g., age and gender) regarding hearing outcomes (self-reported and measurements), and music listening habits (self-reported and measurements) (Studies III and IV).

Wilcoxon's Signed-Rank test was used to evaluate changes in sound level measurements, e.g., preferred listening levels in headphones, between the quiet and noisy test conditions (Study IV).

Linear Regression Analyses were conducted to analyze associations between measured SPLs (independent variable) and hearing thresholds/DPOAEs (dependent variables), before and after adjusting for age and gender as covariates (Study III). It was further used to analyze associations between attitudes to noise (independent variable) and measured SPLs and noise dose (dependent variables) before and after adjusting for age and gender as covariates (Study IV).

Ethical Considerations

The research project was subjected to formal ethical vetting and was approved by the Swedish Ethical Review Authority (Ref. 2020-05274, decision made on October 28, 2020). Thereafter, two applications for amendments were submitted. The first was approved on September 11, 2023 (Ref. 2023-02942-02) and the second on December 19, 2023 (Ref. 2023-07588-02).

The reasons for the amendments were as follows:

Amendment 1) Changing the title of the project and expanding the target group regarding age of recruitment (previous target group was 10-15 years old, and expanded target group was individuals up to 20 years old). The previous specification of the age group “10 – 15 years old” was removed from the title of the project.

Amendment 2) Expanded recruitment strategy to include the ability to post information about the project on the website of region Örebro County and the website *1177.se* (Swedish digital healthcare service platform), as well as being able to distribute informational leaflets at public places where young people gather (for example after-school activities, libraries, music practice, etc.).

For Study II, a separate application for ethical vetting was submitted as the target group and inclusion criteria were slightly different (regarding age range and experience of music listening). The Swedish Ethical Review Authority did not subject the application to formal review but stated that no objections to performance of the study were raised (Ref: 2021-05694-01). Participants nonetheless received information that participation was voluntary and informed written consent was collected prior to the interviews. Research data were handled in accordance with the General Data Protection Regulation (GDPR). Interview materials and transcriptions were securely stored, pseudonymized, and accessible only to relevant project personnel at the Audiological research center. The results are presented in a way that prevents the identification of individual participants.

The data collection and storage of data was in line with regulations of the Swedish Ethical Review Authority and the GDPR. To be able to collect data at an individual level we needed access to personal information such as full name, personal identification number, telephone number, and mail/e-mail address. Personal identification numbers and names were replaced by identification numbers in all data files. The audiological measurements are standardized tests of hearing function that are safe to undergo. No painful, intensely loud, or frightening sounds occurred. All audiological measurements were performed by registered audiologists.

Conducting research with children and adolescents raises several important ethical considerations, particularly regarding autonomy, informed consent, and the potential for emotional discomfort. Although none of the methods used were physically invasive, certain aspects of the data collection might have led to discomfort or unintended consequences in relation to self-awareness of risk behaviors, symptoms, or exposure to clinical/research testing environments.

One potential ethical dilemma lies in the balance between raising awareness and creating concern. Participants were asked about symptoms such as tinnitus or other hearing problems, as well as their music listening habits. This may have caused some participants to reflect on their symptoms and habits, and perceive themselves as at risk, possibly causing distress. This has been noted in previous work involving young participants reporting on health risks [Graham et al., 2013]. All participants were given an overview of their test results after participation. In cases where subjective hearing problems were expressed, we engaged in discussion to address concerns and provide relevant advice. We were also prepared to handle any cases of suspected hearing damage by offering guidance on appropriate referral for further testing. In future studies, this could be further supported by providing brief follow-up information or access to relevant health promotion resources after participation [Bailey et al., 2014].

A central ethical responsibility when conducting research with minors is to ensure that consent is not only formally obtained but meaningfully understood and freely given [CIOMS, 2016]. Although parents/legal guardians provided written consent for participants under the age of 15 years, we also obtained written and verbal consent from the children themselves at the time of participation. The participant information was provided in age-appropriate language and was reviewed with each participant at the start of the session, at which time they were encouraged to ask questions and reminded of their right to withdraw at any stage without consequences. These practices reflect international standards of ethically involving children and adolescents in research [Graham et al., 2013; Powell et al., 2012] and were intended to promote participant autonomy.

Another ethical aspect relates to the sound level measurements in Studies III and IV. Although participants listened to the music at their preferred sound levels in a controlled setting, it was important to ensure that the participation itself did not pose a risk. The SPL measurement protocol was developed to avoid extended or excessive exposure and represent participants' typical music listening habits. A further consideration regards power dynamics. Adolescents may be especially sensitive to perceived authority figures and may feel pressure to respond in a socially desirable way or comply with the researchers' expectations. To address this, data collection was conducted in a manner that emphasized openness, voluntary participation, and confidentiality. Still, these imbalances in research with young people must be reflected upon throughout the research process, including in interpretation of the results.

Results and Discussion

This section includes the main results in relation to the aims of each study, some additional analyses, and a discussion in relation to methodological considerations. Then, the results are integrated and discussed in relation to the overall aim.

In study I, a total of 460 records were identified, 20 of which met the inclusion criteria, risk of bias assessment, and were included in the results. The total sample of the included studies reflected data from 2,939 individuals. Across the 20 studies, the lowest average SPL for PLDs was 46.1 dBA [Alessio et al., 2020], while the highest was 105 dBA [Biassoni et al., 2005]. The SPLs were measured with various methods across the studies, including real-ear measurements, coupler systems, and manikins equipped with ear simulators. The participants reported using a range of headphone types, both within and across studies.

Most of the evidence regarding hearing loss due to recreational noise exposure related to signs of TTS (≥ 15–25 dB HL) for single frequencies above 1 kHz or in the EHF range as well as reduced TE-OAE/DPOAE amplitudes in the EHF range. Associations were identified between the use of PLDs/music listening and early signs of hearing damage in some studies, including higher (worse) hearing thresholds at the EHFs and reduced OAEs/DPOAEs. However, the main findings across all studies were often conflicting and methodological limitations were common. These included a reliance on self-reported exposure data, small sample sizes, and limited use of hearing measurements. Variability in study design, outcome measures, and definitions of “exposure” made comparison of studies difficult. The review concluded that although there is some evidence of early noise-related hearing damage in young people, more studies employing hearing-and sound level measurements are needed to draw conclusions about the exposure-outcome relationship and long-term risks of music listening.

Table 4 shows whether there is evidence of NIHL/changes in hearing thresholds or OAE/DPOAE amplitudes across the included studies, along with a summary of findings.

Table 4. Summary of findings from Study I.

Study reference	Evidence of NIHL/auditory changes	Summary of findings
1. Alessio et al., 2020	Yes	Elevated hearing thresholds ≥ 25 dB HL at 0.25, 4, and 8 kHz, indicating potential auditory damage at specific frequencies directly after music listening.
2. Feder et al., 2013	Yes	Output SPLs were associated with elevated hearing thresholds at 0.5, 1, 2, and 4 kHz, indicating a correlation between PLD use and hearing threshold shifts.
3. Keppler et al., 2010	Yes	Significant changes in hearing thresholds and TEOAE amplitudes after 1 hour of music listening with headphones, showing short-term and immediate effects on hearing function.
4. Kumar et al., 2009	Yes	No significant differences in PTA or DPOAEs between PLD users and non-users but a positive correlation between PTA at 6 kHz and output SPLs, suggesting single frequency impacts.
5. Kumar et al., 2016	Yes	Participants listening at levels > 80 dBA had elevated EHF thresholds and reduced TEOAE amplitudes, indicating higher sound level preference correlating with changes in hearing.
6. Narahari et al., 2017	Yes	Small but significant reduction in DPOAE amplitudes for frequencies 9–12 kHz directly after exposure, suggesting short-term effects on cochlear function.
7. Serra et al., 2005	Yes	Longitudinal study showed mean hearing thresholds increasing, particularly at 14 and 16 kHz, over the course of 4 years with increased participation in music-related activities.
8. Sulaiman et al., 2013	Yes	Correlation found between output SPLs from PLDs and elevated hearing thresholds at EHFs, indicating potential early signs of NIHL.
9. Sulaiman et al., 2014	Yes	Significantly higher mean hearing thresholds at EHFs for PLD users, along with reduced TEOAE and DPOAE amplitudes, suggesting pre-clinical auditory damage.

10. Sulaiman et al., 2015	Yes	PLD users exposed to ≥ 75 dBA showed significantly higher mean hearing thresholds at EHFs compared with non-users.
11. **Keppler et al., 2014**	No	No significant correlation between temporary hearing impairment and efferent suppression after music exposure.
12. Almeida et al., 2020	No	Hearing thresholds within the normal range, suggesting no detectable immediate risk from music listening in noisy environments.
13. Grinn et al., 2017	No	No correlation between noise dose from loud venue attendance and changes in hearing thresholds or DPOAEs.
14. Le Prell et al., 2018	No	No significant relationships between output SPLs and hearing thresholds at 3, 4, or 6 kHz.
15. Mercier & Hohmann, 2002	No	Identified hearing loss in 11 % of the sample but did not link it directly to loud music exposure, indicating the need for further investigation into noise sources.
16. Paping et al., 2021	No	No significant correlation between daily noise dose from PLDs and hearing thresholds.
17. Silva et al., 2018	No	Participants had normal TEOAEs across all frequencies, indicating no detectable impact of PLD use on OAEs.
18. Torre et al., 2014	No	No significant effect on DPOAEs from one hour of music listening with PLDs, suggesting no detectable immediate hearing changes.
19. Trzaskowski et al., 2014	No	No significant changes in OAE amplitudes or pure tone thresholds in relation to output SPLs.
20. Widén et al., 2017	No	Non-significant but slightly elevated mean hearing thresholds for individuals selecting higher sound levels (> 85 dBA LAeq).

The risk of bias assessment of the studies was conducted using two standardized checklists from the SBU [2020], with each study independently reviewed by at least two authors. These checklists are structured around different "risk domains" that target specific potential biases, such as selection bias, attrition bias, and publication bias, offering detailed questions to facilitate the assessment process. Although all domains were considered, particular attention was paid to those deemed most pertinent to each respective study, with assessments made on an individual basis. The overall bias level was then categorized as either low or medium, based on these evaluations. Some studies were assigned a high risk of bias rating due to challenges in assessing certain domains, primarily in relation to exposure data. Studies identified as having a high risk of bias were excluded from the main findings.

The GRADE system categorizes evidence quality or certainty into four levels: very low, low, moderate, or high. Murad et al. [2017] provided guidance on how to qualitatively assess the certainty of evidence when a meta-analysis is not available. By analyzing the significance of GRADE domains, one can determine how these aspects influence the overall confidence in the aggregated evidence [Murad et al., 2017].

The findings of Study II were based on contributions from 7 individuals aged 15 – 19 years (4 female, 3 male). The analysis of the informants' interviews and transcribed materials resulted in three superordinate themes with two subordinate themes each, presented in Table 5 below. The collective narratives consistently revealed that music was an integral part of daily routines, serving as a near constant presence that met various needs. It acted as a means of escape or filled the silence during mundane moments. Further, music was used for managing emotions and reducing anxiety or overstimulation. A common preference among participants was the use of headphones, as they were considered to enhance the loudness, providing a more intense experience. Additionally, music listening in headphones creates a personal space, helping individuals to avoid engaging socially with people in public or to reduce unwanted background noise. The participants' exhibited some awareness and a basic understanding of the hearing health risks associated with music listening, but the significant role that music played in life seemed to outweigh any concern about future hearing problems.

Table 5. Resulting themes in Study II.

Superordinate themes	**Music and state of mind**	**Music and individuality**	**Music enjoyment and hearing-related risks**
Subordinate themes	*- Emotion regulation* *- Cognitive enhancement*	*- Identity formation* *- Peer acceptance*	*- Risk awareness* *- Hearing-health consequences*

The main findings from Study II showed that music held a deep personal meaning for the adolescents, serving as a central tool for emotional regulation, identity development, and managing daily stress. Music listening was embedded into routines, e.g., getting ready for the day, during commutes to school, studying, exercising, and sleeping. Private headphone music listening was often used to create a personal space with emotional safety and control. Despite varying levels of self-reported symptoms like tinnitus and sound sensitivity among the participants, they demonstrated limited awareness of hearing-related risks and consequences and did not seem to perceive themselves as particularly vulnerable. A tension emerged between valuing the benefits of music and acknowledging the potential for hearing damage. This is illustrated in the following quote by participant #7:

> *I need to have a very high volume because otherwise, I can't hear properly at all, and then I don't shut out the other sounds in the same way. So right now, I mostly listen at maximum volume. I don't know if it's really good for my ears, but it's to shut out all the other noises*.

This quote captures the generally low risk awareness expressed by several participants. Moreover, most participants reported that they rarely thought or worried about their hearing health in everyday life and seldom discussed loud music listening with their peers. Peer expectation and fear of judgment also seemed to influence how and where music was listened to. This suggests that individual awareness may only be one part of the picture; adolescents' listening habits may also be influenced by their social environment where peer norms can shape choices and perception of risks.

The analysis (following the steps outlined by Smith et al. [2009; 2022] was iterative and interpretative involving continuous movement between individual cases and cross-case comparisons. First, within each case, after listening to the recording and noting initial thoughts, the researcher read and re-read the transcripts, making exploratory comments in the margins. These could range from descriptive observations (for example "participant mentions feeling calm when using headphones for music listening") to more interpretative reflections (such as "music is used as buffer against social anxiety").

From these readings and observations, experiential statements within each case were made to capture essential meanings, such as “music is a daily tool for emotional regulation” or “headphones can be used as a signal to others to be left alone”. These statements were clustered into emerging thematic patterns. Building on the examples of experiential statements above, within-case themes included “The comfort of isolation through headphones” and “Music as an emotional anchor.” The emerging themes were compared across cases to identify shared group-level themes, leading to superordinate themes such as “Music as a coping mechanism”. Superordinate themes were created based on both the prevalence of similar themes across interviews and the interpretative richness, e.g., the themes’ ability to offer meaningful insight into the research aims. The final themes, presented in the findings section of Study II, were refined through a process of returning to the transcripts, experiential statements and group-level synthesis.

Co-judging within the research group, note-taking during interviews and note-/memo-writing during transcription were methods used to ensure analytical transparency and traceability. Credibility was supported by close alignment between the themes and the participants’ narratives. Dependability was ensured through a co-judging process among the authors, and confirmability through documentation of the analytical process. The sample consisted of a purposively selected group of adolescents who were relatively close in age, shared an interest in listening to and/or playing music, and shared a similar background (some were enrolled in the same upper secondary schools, and most participants reported having at least one parent with higher education). Although the findings were rich in experiential depth, their transferability is limited. The findings are primarily applicable to similar demographic and contextual settings and may not reflect the experiences of more diverse or socioeconomically disadvantaged youth.

Study III investigated participants’ headphone listening levels and hearing function. Participant characteristics and baseline hearing data are summarized in Table 6, whereas SPL measurement results are presented in Table 7. In addition to age and gender distribution, participants’ socioeconomic background was investigated using

Demographic Statistical Areas (DeSO). DeSO is a classification system from Statistics Sweden (SCB) that provides area-level indicators of education and income. Data were retrieved from the DeSO database [SCB, 2023]. The result showed homogenous samples in terms of socioeconomic background, with most participants residing in areas characterized by medium to high levels of parental education and income, based on the normalized DeSO index scores.

The results of Study III showed that most participants selected sound levels below the WHO reference exposure limit (< 70 dBA) and estimated noise doses were generally low. However, older participants (15 – 20 years) had higher EHF thresholds, higher measured SPLs (in the quiet test condition), and reported more frequent music listening at high sound levels compared with the younger participants. Reduced DPOAEs were primarily observed at the highest tested frequencies (7996 and 9509 Hz). No statistically significant associations were found between measured SPLs or estimated noise dose and hearing thresholds or DPOAEs. These findings suggest that even in cases where early signs of noise-related effects may be emerging, more sensitive diagnostic tools and repeated measured over time are needed to detect subtle changes in auditory functioning. Study III benefited from the use of hearing measurements, including audiometry up to 16 kHz and DPOAEs, as well as real-time SPL measurements in both quiet and noisy test conditions using participants' own headphones. This provided a valuable baseline description of listening habits and hearing function. However, the sample size was small (n = 53), which may have limited statistical power and the ability to detect associations between exposure and outcome.

Additionally, estimated noise dose was based on self-reported listening durations, which may be subject to bias. The cross-sectional design prevents conclusions about causality or long-term effects. The majority of studies in this field tend to focus on "direct" relationships between headphone music listening and hearing function, primarily capturing short-term impacts [e.g., Keppler et al, 2010]. This trend highlights a methodological challenge in the field, i.e., measuring noise exposure accurately [Fligor, 2009]. Although it is relatively straightforward to measure noise levels in the ear canal, obtaining precise measurements of all forms of recreational noise exposure remains a complex task [Neitzel & Fligor, 2019]. Such complexities include the variability in environmental noise levels, the type of headphones used, and individual listening habits, including the life course perspective (when they started being exposed to loud noise/music and how long they have been exposed) which collectively contribute to the overall noise exposure.

Four different types of headphones were used by the study participants during the sound level measurements. The types were noted for 52/53 participants. Supra-aural types were used by 16 participants (31 %), concha-types by 15 participants (29 %), circum-aural types by 8 participants (15 %) and in-ear/canal types by 13 participants (25 %). The types of PLDs among those who brought their own were usually smartphones; in one case, an iPad was used. The mean measured SPLs were examined across the four headphone types in both test conditions (see Table 8).

In the quiet test condition, in-ear/canal headphones were associated with the highest mean sound level (63.4 dBA) and supra-aural headphones with the lowest mean levels (61.0 dBA). In the noisy test condition, circum-aural headphones showed the highest mean level (70.0 dBA), and in-ear/canal headphones showed the lowest mean level (65.5 dBA). The in-ear/canal types also showed the smallest increase in sound level when comparing the quiet test condition with the noisy test condition. These differences may reflect the characteristics of the headphones; the greater noise isolating effect of in-ear/canal types may reduce the need for sound level increases in noisy settings. Meanwhile, circum-aural and concha headphones, which allow more background noise to pass through, may be used at higher sound levels to compensate for background noise interference. This is consistent with recent findings by Amarante and Zalewski [2025] showing that over-the-ear (circum-aural) headphones generated lower SPLs at the tympanic membrane, suggesting that using these headphones may require compensating by increasing sound level, particularly in noisy environments. Conversely, in-ear (canal) headphones, which tend to generate higher in-ear SPLs, were associated with smaller increases in sound level between quiet and noisy test conditions, possible due to greater passive noise isolation. This emphasizes how headphone output capabilities may influence not only the sound energy delivered to the ear, but also user behavior in adjusting preferred listening levels.

In Study III, a Kruskal-Wallis test showed no statistically significant differences in mean sound levels between the four headphone types in either test condition. Given the small sample size, the overall findings should be interpreted with caution. However, they point to an interesting direction for future research in testing whether headphone type significantly affects measured SPLs under different environmental conditions in a larger sample.

Another important aspect to consider when interpreting the results of SPL measurements is the equipment used, as there are advantages and disadvantages to different methods. Real-ear measurements, which capture SPLs directly at the eardrum, provide more accurate measures of the sound exposure experienced by the individual [Keppler et a., 2010]. Conversely, advantages of KEMAR measurements include standardization and consistent comparisons across studies and test conditions in a non-invasive way. Another aspect to consider in measuring music exposure is that different recordings have varying average loudness and peak values depending on the type of recording or spectral and temporal differences [Fligor & Cox, 2004]. Furthermore, laboratory-based SPL measurements assume that listeners' preferred songs or listening levels do not vary, depending on the environment, it is however likely that these preferences change in response to different environments [Washnik et al., 2021; Berger et al., 2009].

Table 6. Participant information (Studies III and IV).

Variable	N (%)	Mean (SD)
Total participants	71 (100 %)	
- Participated in SPL & hearing measurements	53 (75 %)	
Age		
- Age range, years		10–20, 13.9 (2.5)
- 10–14 years	40 (56 %)	
- 15–20 years	31 (44 %)	
Gender		
- Female	41 (58 %)	
- Male	30 (42 %)	
PTA 0.5–4 kHz		
- Right ear (dB HL)		0.7 (4.06)
- Left ear (dB HL)		-0.3 (4.03)
Mean EHF thresholds (9 – 16 kHz)		
- Right ear (dB HL)		2.0 (7.7)
- Left ear (dB HL)		1.7 (7.8)

Table 7. Mean SPL measurements (LAeq) from participants' headphones.

Test condition	Min SPL (dBA)	Max SPL (dBA)	Mean (SD) SPL (dBA)	N, % < 70 dBA
Quiet	44.6	90.0	61.8 (10.4)	38 (73 %)
Noisy	45.5	93.1	67.2 (9.3)	33 (67 %)

Table 8. Mean measured SPLs (dBA) by headphone type.

Headphone type	Mean dBA in quiet	Mean dBA in noise	Mean dB(A) increase in noise
Concha (semi-open, in the bowl of the outer ear)	62.3	69.1	6.8
Supra-aural (placed on top of outer ear)	61.0	66.6	5.6
Circum-aural (over-ear, encloses the outer ear)	62.0	70.0	8.0
In-ear/canal (insert)	63.4	65.5	2.0

The main findings of Study IV were that attitudes to noise were significantly associated with self-reported music listening habits and with higher measured headphone listening levels, even after controlling for age and gender. Participants with more positive attitudes toward noise tended to listen at higher sound levels, particularly those in the older age group (15 – 20 years) who also reported more frequent use of headphones and longer daily listening durations. A Wilcoxon Signed Rank test indicated a statistically significant increase in measured SPLs between quiet and noisy test conditions ($Z = 5.20$, $p = <.001$) with 39 participants (73.6 %) increasing the preferred sound level in noise.

Self-reported auditory symptoms were examined in relation to both self-reported music listening habits and measured SPLs/noise dose (see Table 9 for a description of how the auditory symptoms were measured). Mann-Whitney U tests showed that individuals with higher sound-induced auditory fatigue also reported more frequent music listening at high sound levels (in radio/stereo) ($Z = -1.997$, $p = .046$). Individuals with tinnitus (reported as yes/no) had a significantly higher mean rank compared with those without tinnitus (49.00 versus 26.92) when reporting daily music listening duration with headphones ($Z = -2.623$, $p = .009$).

Spearman’s rank correlation analysis showed that individuals who reported permanent tinnitus were more likely to prefer lower SPLs in the quiet test condition, as indicated by a moderate negative correlation (ρ = -0.305, p = .028). Tinnitus was also significantly correlated to noise dose, showing negative correlations in both quiet (ρ = -0.394, p = .008) and noisy test conditions (ρ = -0.351, p = .019). In contrast, those who reported attenuated auditory sensation (following noise exposure) tended to have higher noise doses in both test conditions, but not with measured SPLs alone. Sound-induced auditory fatigue, need for auditory recovery and sound sensitivity (hyperacusis) did not show any significant correlations with measured SPLs or noise, indicating no clear relationship between these symptoms and music listening in the tested conditions. However, participants with greater need for auditory recovery had significantly worse DPOAEs in both ears.

The regression models showed that attitudes to noise explained between 13 % and 26 % of the variance in measured SPLs. These results suggest that individual attitudes and age-related trends may play a central role in shaping risky music listening behaviors before detectable changes in hearing thresholds appear. The results also support findings from earlier studies suggesting that more tolerant attitudes toward noise may reflect or reinforce more risky music listening behaviors [Widén et al., 2009; Vogel et al., 2011].

Table 9. Overview of auditory symptom measures.

Auditory symptom	Questionnaire item	Response option
Tinnitus	Do you have persistent tinnitus (ringing or buzzing in your head or ears) that doesn't go away?	Yes/No
Attenuated auditory sensation	Have you experienced a feeling of blocked ears (where sound seems weaker or muffled compared to the usual) after being exposed to noise or loud music?	Never / Rarely / Rather often / Often / Always or almost always
Sound-induced auditory fatigue	How often do you experience sound fatigue (a feeling of mental exhaustion caused by too much noise around you)?	Never / Occasionally, once a month or less / Occasionally, once a week or less / Several times a week / Daily
Need for auditory recovery/rest	How often do you feel the need to take a break from sounds (prefer a quiet or calm environment or avoid listening to things like the radio or music)?	Never / Occasionally, once a month or less / Occasionally, once a week or less / Several times a week / Daily
Sound sensitivity (**hyperacusis**)	How often do you experience sound sensitivity (discomfort or pain in your ears from everyday noises)?	Never / Occasionally, once a month or less / Occasionally, once a week or less / Several times a week / Daily

This study combined self-reported data as well as hearing-and sound level measurements, which allowed for a multidimensional analysis of factors related to music listening behavior. A strength was that the measured SPLs were assessed in relation to attitudes to noise, which to our knowledge, has not been studied before. However, self-reported symptoms and some music listening habits are subject to recall bias and social desirability bias. For example, when participants are asked to set their typical listening levels in a test setting, they may choose a lower level than they would in everyday life, leading to an underestimation of actual exposure [Punch et al., 2011; Widén et al., 2009].

The cross-sectional design limits causal interpretations. Further, although the sample included a wide age range, the overall group was relatively homogenous, and no participants had diagnosed hearing loss. The attitudes to noise scale had high internal consistency and the pattern of response suggested a general tendency toward acceptance of loud music/sound environments. The PCA indicated possible subdimensions, but the coherence of the full scale supported the use of a composite score in this context. However, one component (reflecting noise regulation and protective intentions) was defined by only two items with modest loadings, and some items lowered the internal consistency of the scale (e.g., item no. 11). These aspects may require revision or removal in future studies, but further validation of factor structure will require larger sample sizes. Despite these limitations, the study contributes with valuable insights into behavioral and perceptual factors that may influence early hearing health outcomes among young people.

To enable future longitudinal follow-ups, participants with hearing thresholds within the range of 0–25 dB HL were included in the studies involving hearing measurements (Studies III and IV). Though stricter thresholds, e.g., ≤ 15 or 20 dB HL are sometimes referenced for pediatric populations (up to 18 years old) to account for developmental needs [Northern & Downs, 2014], the 25 dB HL threshold was consistent with most studies included in the systematic review (Study I). No separate analyses were conducted using a stricter cutoff, but the hearing data showed that most participants had thresholds below both 15 and 20 dB HL, with only a few outlier values. Given that hearing thresholds were analyzed as continuous variables across frequencies and not used to define subgroups with varying degrees of hearing loss, the main findings would likely not have differed with a more conservative criterion.

Establishing individual baseline data in this manner allows for the identification of subtle changes in hearing function that may not yet be detectable. This is particularly important in preventive audiology, where early detection of changes in EHF thresholds or OHC function (e.g., via DPOAEs) may offer crucial insights into early stages of NIHL. In this way, the collected data can serve as a reference point in prospective assessments of hearing health and may contribute to a more nuanced understanding of how risky music listening behaviors influence auditory outcomes over time. However, future research could benefit from also including individuals with clinically diagnosed hearing loss, to examine whether the observed patterns of music exposure differ between groups with and without hearing loss.

Discussion of Overall Research Aim

Taken together, the four studies offer complementary perspectives on young people's music listening habits, perceptions of noise and risk, and potential early indicators of noise-related hearing damage. Whereas Study I synthesized existing evidence on recreational noise exposure and hearing outcomes, Study II provided in-depth insights into the emotional and cognitive significance of music and adolescents' limited risk awareness. Studies III and IV contributed with empirical data on habits and symptoms related to hearing- and sound level measurements.

In Study IV, attitudes to noise were significantly associated with both self-reported and measured headphone SPLs, suggesting that more positive or tolerant attitudes may correspond to a greater acceptance of higher sound levels. From a theoretical perspective, such attitudes could also be related to lower perceived susceptibility to harm, in line with a belief that one is personally unlikely to experience negative consequences from high sound levels. TPB components such as subjective norms and perceived behavioral control may help explain the observed behaviors. Moreover, the HBM construct of self-efficacy, the belief in one's ability to take preventive action or exert control over one's behavior, may help explain the gap between awareness/knowledge and music listening behavior seen in Study II.

Participants acknowledged potential risks but did not show indications of plans to modify their behaviors, suggesting that even when risk is considered, a lack of perceived control or competing motivations (e.g., emotional regulation, identity expression) may override caution. Study II further revealed that music plays a complex and deeply valued role in an adolescents' life, often associated with identity and emotion regulation. These insights reflect broader determinants of behavior and challenge prevention efforts that rely solely on risk information. Adolescents' willingness to tolerate symptoms such as temporary tinnitus may reflect a lower perceived severity, or the high value placed on music as a coping strategy.

From an ICF perspective [WHO, 2001], the findings point to the relevance of taking self-reported hearing problems into account, especially in the absence of TTS or PTS. Participants (in Studies II and IV) described and reported auditory symptoms such as tinnitus, sound sensitivity or noise fatigue, yet these were not always reflected in the hearing measurements. Overall, the findings showed that auditory symptoms such as sound sensitivity and the need for auditory recovery were relatively common, even among participants with hearing thresholds < 25 dB HL. Furthermore, although Study III found no statistically significant associations between measured SPLs and hearing thresholds or DPOAEs, subtle trends, such as elevated (worse) EHF thresholds were present in older participants. These observations align with growing evidence of HHL and the limitations of standard audiometry in detecting early cochlear damage [Liberman et al., 2016], reinforcing the notion that traditional definitions of "normal hearing" may ignore relevant functional difficulties.

From a disability research perspective, these early symptoms and listening behaviors may increase the risk of future activity limitations, particularly in communication-intensive or noisy environments like schools or workplaces. Therefore, preventive strategies should target the individual level, for example by addressing attitudes, behaviors, and risk awareness, but also the environmental level, for example through noise regulations and addressing beliefs and norms that normalize or promote loud music listening. As hearing loss can negatively affect social participation, well-being, and educational or occupational outcomes, preventing hearing loss is a way to limit disability and promote functioning [WHO, 2001]. This includes promoting functioning and participation through early identification and reduction of risk behaviors before NIHL develops.

Age and gender differences also emerged across the studies, particularly in relation to reported behaviors and attitudes. For analytical purposes, gender was treated as a binary variable (male/female), reflecting both the coding structure used in the dataset and the circumstance that no participants identified outside this binary. However, this should not be interpreted as a statement about biological sex being correlated with hearing outcomes. Instead, potential differences observed between groups may be better understood through a gendered perspective, considering how sociocultural norms and expectations can influence listening habits, attitudes to noise, and engagement in risk-related behaviors [Widén et al., 2006]. Although gender differences were limited, boys reported longer listening durations and higher SPLs overall. Studies III and IV showed that older participants more frequently reported listening to high sound levels, had more positive attitudes to noise, and longer daily durations of headphone use. Taken together, these findings suggest that demographic factors may influence exposure patterns but are not necessarily consistent predictors of hearing outcomes, reflecting mixed evidence in previous research [e.g., Vogel et al., 2011; Punch et al., 2011].

An important conceptual theme in this thesis is the distinction between music and noise. Although music is classified as sound, and thus also "noise", it is mainly perceived as enjoyable and meaningful by many people. This may obscure its potential for harm, especially in the context of repeated exposure to high sound levels. In this context, it is also important to consider that noise exposure below 70 dBA cannot be assumed to be entirely "safe." Studies have indicated that prolonged exposure to leisure noise sources at 50-55 dBA may have adverse health effects, and sound levels at or above 70 dBA may contribute to hearing-related risks over time, especially [Flamme et al., 2012; Portnuff et al., 2011]. Cumulative noise exposure in everyday contexts where music listening occurs for extended periods, warrants caution even when levels are below existing guidelines and in relation to a potential trend in preferring higher sound levels in noisy environments. These results reflect trends observed in previous research [Feder et al., 2021; You et al., 2020] and raise concerns about potential cumulative effects.

Another important distinction to consider is the difference between being exposed to risk and actively engaging in risk-taking behavior. Though exposure to loud music can occur passively in various social and environmental contexts, risk-taking involves a degree of choice, intention and often awareness of potential harm [Gulliver et al., 2010; Gilles et al., 2012]. The TPB is particularly relevant here, as it frames behavior as a function of attitudes, perceived norms, and perceived control, e.g., it takes both individual intention and social influences into consideration [Ajzen, 1991]. Young people who choose to listen to loud music, despite awareness of possible harm or even experience of auditory symptoms, may be engaging in deliberate risk-taking. In contrast, others may be involuntarily exposed to high sound levels without perceiving their behavior as risky [Vogel et al., 2010; Widén et al., 2013].

Moreover, as illustrated in Study II, music listening can fulfill emotional and psychological needs, which adds complexity to how risk is perceived and navigated. When used as a coping strategy, for example to manage stress or create a sense of "escape" inward, the choice to listen to loud music may not be experienced as risky, even if it involves high sound levels. Previous research shows that music can have positive effects on mood, quality of life, and mental health [Daykin et al., 2018; Garrido et al., 2022; Schäfer et al., 2013]. Given that the participants' in Study II described music as emotionally rewarding and sometimes even necessary in daily life, it raises questions about how emotional needs interact with risk perception. The emotional benefits of music may create a positive health-related belief, which in turn may downplay the perceived risks of long-term exposure or high sound levels. Taken together, these findings point to the importance of considering hearing health as part of a broader picture of adolescent well-being. To better address risky listening behaviors, preventive strategies may benefit from recognizing that behaviors seen as risky in clinical terms may serve self-regulatory functions in the lived experiences of young people.

Collectively, the findings support the overall aim of the thesis: to examine how music listening habits, attitudes to noise, and self-reported auditory symptoms relate to hearing outcomes. By integrating behavioral aspects and audiological measures, this work contributes to a more comprehensive understanding of hearing health in young people and highlights the need for prevention strategies that are both evidence-based and contextually sensitive.

Strengths and Limitations

The recruitment of participants for Studies III and IV was conducted through the various platforms and organizations described earlier. The outbreak of the COVID-19 pandemic required unexpected adjustments to the research methodology, impacting the planned approach. The initial plan was to employ a longitudinal approach in the quantitative studies (III and IV). However, the public health guidelines and restrictions in response to the pandemic prevented collection of data in the manner intended. In response, a plan was formed to conduct a systematic review instead. This allowed us to analyze existing data comprehensively, aiming to maintain the momentum of the project despite the inability to gather new data.

To address the recruitment challenges, alternative strategies were explored, such as distributing information about the project to schools by sending information mail/letters to the administration/teachers, and later (2024) sharing a link to information about the project on 1177.se. In addition, while the pandemic restrictions were in place (2020 – 2021), we attempted to focus exclusively on the questionnaire component of the quantitative data collection, as participants could complete this remotely. However, this adjustment only partly improved the recruitment bottleneck. Data collection continued for a longer time than planned and at a slower pace than ideal.

The focus on a single geographical location (central Örebro) may have introduced a degree of selection bias, impacting the external validity [Galea & Tracy, 2007]. Future recruitment efforts will continue to target a wide range of participants to broaden the demographic diversity of the sample [Ford et al., 2008]. Including self-reported questionnaire data in any research project will introduce potential biases, including recall bias and social desirability bias [Gnambs & Kaspar, 2015; Stone & Shiffman, 2002]. To minimize recall bias, questions regarding music listening habits were articulated around manageable time frames such as hours and minutes, and frequency of music listening per day. To minimize social desirability bias, participants were assured of the anonymity and confidentiality of their contributions.

The relatively cautious music listening behaviors observed in Studies III and IV, with a majority of measured SPLs being below or aligned with reference exposure limits, may partly reflect the socioeconomic background of the participants. Previous research has indicated that higher parental education and socioeconomic status are associated with greater awareness of health risks and more proactive health behaviors [Vogel et al., 2010; Dreher et al., 2018; Olsen-Widén & Erlandsson, 2004]. The predominance of participants from socioeconomically advantaged areas may have influenced their attitudes toward noise and risk perception, contributing to more protective behaviors.

One challenge in the regression analyses (Studies III and IV) was the limited sample size (N = 53 in most analyses and N = 45 in analyses relating to noise dose) which reduced statistical power and limited the number of covariates that could be included without risk of overfitting [Field, 2017, p. 531]. Variability in headphone types and listening contexts may also have introduced unaccounted heterogeneity in SPL measurements. Nevertheless, Studies III and IV provide a valuable contribution by combining measures of both exposure and outcome. Continued accumulation of such evidence is necessary to strengthen our understanding of the associations between music listening and early indicators of NIHL. Another strength was the use of participants' own headphones and PLDs, instead of standard headphones for all participants, as it provides a realistic reflection and assessment of their real-world listening environments and habits.

Conclusions and Implications

The overall findings of this thesis provide a nuanced view of recreational noise exposure and its potential implications for hearing health. The central narrative that emerges is how hearing health among young people can be affected not only by noise exposure, but also by how they think about, relate to, and value noise, especially music. Adolescents and young adults often engage in potentially harmful listening behaviors and report limited concern about their future hearing health, despite sometimes experiencing tinnitus, sound sensitivity, or TTS. These behaviors seem to be influenced by attitudes, peer norms, and the emotional meaning of music, rather than solely risk awareness. The results also emphasize that subjective hearing problems and early auditory symptoms can exist and should be taken seriously even when audiograms are within standard clinical limits. The integration of behavioral considerations with audiological data contributes to a broader understanding of potentially risky music listening behaviors. The use of SPL measurements, EHF, DPOAEs and self-reported symptoms offers a multidimensional perspective on hearing health among young people. Taken together, these insights support a more person-centered perspective on hearing health, complementing impairment-based approaches.

In relation to clinical practice, the findings do not offer direct answers to common questions asked by patients such as *"How loud is too loud?"* or *"What amount of music listening/headphone use is safe?"* The variability in individual susceptibility, and differences in factors such as music listening contexts, headphone types, and measurement methods, makes it difficult to define universal thresholds and standards for safe music listening. Additionally, even sound levels considered "safe" according to current guidelines may pose a risk under certain conditions. Therefore, audiologists must balance available evidence with individual considerations, and communicate risk in a way that is transparent, realistic, and sensitive to the needs of the patients. However, despite these limitations, the results point to the importance of integrating EHF and OAEs, as well as considering self-reported auditory symptoms as part of a complete hearing assessments.

Concrete intervention strategies are still emerging, and this thesis supports a move toward youth-informed or youth-collaborative approaches. Interventions should not rely on fear-based messages but instead focus on risk awareness as well as autonomy. Promising strategies include educational messaging paired with feedback tools (interactive smartphone apps) and personalized risk assessments in consultation with audiologists [Punch et al., 2011; Breinbauer et al., 2021].

Future Directions

Longitudinal studies are necessary in order to determine how early indicators of NIHL, and behavioral trends predict future hearing outcomes. Further research is needed to evaluate the effectiveness of interventions targeting attitudes, behaviors, and peer norms. Future studies should explore diverse populations and contexts, including underrepresented groups, where risk and access to prevention or knowledge on hearing health may differ. Another important avenue for future research is technology-based monitoring tools that could offer real-time feedback about music listening habits and promote self-regulation.

In summary, this thesis contributes to a growing body of research on the complex interaction between music listening habits, hearing health and risk factors among children, adolescents, and young adults. The findings suggest that even when clinical hearing thresholds may remain within “normal” limits, the presence of early signs of auditory damage and risky music listening behaviors warrant attention. Promoting hearing health in young people requires not only preventive strategies and personally tailored interventions but also an understanding of all aspects of the meaningful role of music in the everyday life of young people.

Acknowledgements

I would like to express my gratitude to all the individuals and institutions that supported me throughout the course of this work. First I want to thank my main supervisor, Stephen Widén, who has been an exceptional guide; thank you for your passion for this research, always making time for me, and trusting me to work in my own way. To my co-supervisor, Elina Mäki-Torkko, thank you for your generous availability, helpful feedback, and encouragement that gave me confidence along the way. To my second co-supervisor, Kerstin Persson Waye, thank you for the consistently thorough and thoughtful advice; your expertise strengthened fundamental parts of this work. I also wish to thank Staffan Bengtsson, a key co-author, whose insight encouraged me to view this research area through a broader lens, enhancing the quality of the work. Thank you also to another key co-author, Sarah Granberg, whose experience and knowledge helped lay a strong foundation in the early stages of the project.

To all research administrators, research audiologists, and engineers, thank you for the vast expertise, time, and practical support you provided during some of the most vital phases.

This project would not have been possible without the support of all the funding organizations, and certainly not without the participants, whose contributions were essential.

Lastly but most importantly, to my family and loved ones, you have been the main source of support with your belief in me. Thank you for being relentless reminders of what truly matters.

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