Aspects of professional functioning in employees with hearing loss

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General introduction

Hearing loss

With a prevalence estimate of 1.3 billion adults worldwide, hearing loss is the most common sensory impairment in humans (Ciorba et al., 2012; James et al., 2018). Hearing loss can be related to the anatomy and physiology of the ear, but it can also affect the hearing function, functioning in everyday activities, and participation in life situations (Dillon, 2008). Therefore, hearing can be considered to be a sociocultural phenomenon, rather than an isolated medical problem (Danermark et al., 2013; Granberg et al., 2014).

Anatomy and physiology

The term hearing loss is used to describe an impairment of one or both ears that results in hearing difficulties. Depending on where the impairment is located, three types of hearing loss can be distinguished: conductive, sensorineural, and mixed hearing loss (Michels et al., 2019). Conductive hearing loss results from a disruption in the ear canal and/or the middle ear, causing sounds to be conducted inefficiently to the inner ear. Possible causes are obstruction of the ear canal – for example by cerumen – or middle ear diseases, such as otitis media. The more common type of hearing loss, sensorineural hearing loss, involves a distorted conversion of sounds in the inner ear and/or the auditory nerve and is most often caused by ageing or by excessive noise exposure (Rabinowitz, 2000). If conductive and sensorineural hearing loss occur in combination it is called mixed hearing loss.

Hearing loss can be related to tinnitus or hyperacusis, ear disorders that may share their pathophysiology with that of hearing loss (Nelson & Chen, 2004). One of the possible explanations is that sensorineural hearing loss causes the brain to receive an incongruous neural message. As a reaction, the brain may 'turn up the volume' resulting in either everyday sounds being perceived too loud, even painfully so (hyperacusis) or a persistent perception of a sound that has no external source (tinnitus) (Baguley et al., 2013; Sheldrake et al., 2015). Although most individuals with hyperacusis or tinnitus also suffer from hearing loss, hyperacusis and tinnitus can also occur in isolation.

Hearing function

For both conductive and sensorineural hearing loss, reduced sensitivity of sounds is the most obvious symptom, requiring soft sounds to be louder to be heard.

Yet, in case of sensorineural hearing loss, an additional effect is that the distorted conversion of sounds to the brain often causes sounds to be perceived as blurred (Dillon, 2008). Also, discomfort can be experienced when loud sounds are heard, even at levels that are not perceived as annoying by normally-hearing individuals (Levitt, 2001). Consequently, sensorineural hearing loss is characterized by a reduced dynamic range of hearing, meaning that the range between the weakest sound that can be heard and the most intense sound that can be tolerated is often smaller when sensorineural hearing loss is present (Dillon, 2008).

Sensorineural hearing loss involves problems with multiple auditory functions that contribute to further distortion of sounds (Dillon, 2008; Plomp, 1978). These auditory functions – specifically spectral, temporal, and spatial resolution – partly share their cause, but affect auditory functioning in different ways. Decreased spectral resolution causes difficulties with recognizing two separate sounds of a different frequency that are presented simultaneously. Decreased spectral and temporal resolution cause the distortion of sounds and difficulties with listening selectively, for example with understanding speech in noise. Lastly, decreased spatial resolution causes a higher sensitivity for loud sounds and causes difficulties with spatial hearing.

The impact of hearing loss on hearing function depends on whether one (unilateral hearing loss) or both ears (bilateral hearing loss) are affected. Bilateral hearing loss is most common and results in reduced hearing function as described above. When normal hearing is present in one ear, the reduced sensitivity of sounds is rather modest. Unilateral hearing loss often results in no more than a small attenuation of sounds presented at the affected side, since sounds need to travel around the head to the opposite ear. However, unilateral hearing loss may lead to specific difficulties in case of adverse listening situations. When information of only one ear can be used, it can become more difficult to recognize the meaningful sounds and to filter out the environmental noise (Sargent et al., 2001). Also, unilateral hearing loss causes difficulties with locating a sound source, since the brain needs input of two ears to accurately determine the direction where a signal originates.

Personal and environmental factors

Many personal and environmental factors interact with hearing loss and its impact on hearing functions, everyday activities, and participation in life situations (Granberg, 2015). In other words, the degree of hearing loss as well as the impact of hearing loss on daily life functioning depends on personal and environmental factors. These factors include the presence of environmental noise and reverberation, the use of hearing aids or other assistive technical devices, social support, and the use of compensatory strategies, such as making use of speech reading skills. The impact of hearing loss on work functioning can also be greatly influenced by personal and environmental factors (Granberg & Gustafsson, 2021). For example, a workplace with facilitators – such as supporting colleagues or hearing devices – can improve auditory functioning at work, whereas a workplace with barriers – such as a noisy environment or high auditory demands – can restrict auditory functioning at work. Although there is little knowledge on how personal and environmental factors interact with hearing loss and its consequences on everyday activities and participation in working adults with hearing loss, environmental noise and reverberation have been described to be important factors to consider in this population (Dobie, 2008; Morata et al., 2005).

Noise and reverberation

Noise can be defined as any unwanted sound that interferes with the sound of interest (Levitt, 2001). When listening to someone's speech, possible sources of noise are interfering voices, or sounds produced by technical devices in or near by the room. Many job tasks need to be performed in noisy work environments. This is evident in the case of a call-center agent who needs to make phone calls simultaneously with many colleagues in the same room (Beyan et al., 2016), in the case of a nurse who needs to detect 23 different auditory alarms at an intensive care unit (Momtahan et al., 1993), and in the case of a team leader who needs to participate in staff meetings (Laroche & Garcia, 2001).

Reverberation occurs when a sound source is accompanied by reflections of multiple sound sources in an enclosed space (Perham et al., 2007). It can be expressed in reverberation time, which is the time it takes for a sound to reduce 60 dB below its original level. The reverberation time depends on the size, shape, and nature of the room. For example, the reverberation time is often higher in rooms with high ceilings and hard surfaces, whereas the reverberation time can be reduced by placing sound-absorbing materials, such as curtains or carpeting. A considerable amount of job tasks is performed in reverberant listening environments, including swimming pools, open offices, and sport halls.

Noise and reverberation complicate the performance of everyday activities that rely on hearing function. In the case of sensorineural hearing loss, this can be explained by the decreased temporal, spectral, and spatial resolution (Dillon, 2008; Plomp, 1978). Temporal, spectral, and spatial resolution are especially required in noisy environments, with multiple simultaneous or subsequent sounds present. Listening effort increases in the attempt to compensate for the adverse effects of noise, causing participation in noisy situations to be more demanding and fatiguing (Beechey et al., 2020; Hornsby et al., 2016; McGarrigle et al., 2014). Unfortunately, the adverse effects of noise and reverberation can often not be fully compensated for by using extra listening effort; the difficulties with performing auditory tasks often remain in noisy situations.

Noise can cause difficulties with performing auditory tasks, but higher noise levels are also associated with increased annoyance and distraction as well as decreased concentration, productivity, and working capacity (Sailer & Hassenzahl, 2000). This is particularly the case in industrial workers, shipyard workers, construction workers, military workers, and farmers (Lie et al., 2016). However, even noise at lower sound levels can cause these negative effects, especially when the complexity of the job task is high (Beaman, 2005; Landström et al., 1995). For example, office workers can be distracted by office noise, particularly from telephone ringing and others talking in the background (Banbury & Berry, 2005; Sundstrom et al., 1994).

Individuals that are exposed to occupational noise are at risk for developing noise-induced hearing loss. It is estimated that eight percent of the Dutch work-force is repeatedly being exposed to excessive noise levels at their workplace (Hooftman et al., 2020). Excessive noise exposure may directly result in a temporary reduction of hearing sensitivity, which is called a temporary threshold shift . This temporary threshold shift will largely disappear within 48 hours after the noise exposure if the ear is given enough rest (Mirza et al., 2018). However, if the noise exposure is persistent, permanent noise-induced hearing loss will likely occur. This is called a permanent threshold shift. Other harmful effects of occupational noise exposure are tinnitus and hyperacusis.

Activities and participation

Activities

Hearing loss may affect the performance of everyday activities that rely on sufficient hearing function (Granberg, 2015). For instance, reduced sensitivity and distortion of sounds may result in difficulties with speech understanding during conversations with one or more persons, and the reduced ability to locate sounds may make it difficult to hear cars coming when walking through traffic. Other activities that may be affected by hearing loss are the usage of telecommunication devices and communication strategies, interactions with family or strangers, or interactions in formal relationships.

Granberg (2015) investigated everyday activities that are most commonly affected in adults with hearing loss. Her research was performed within the framework of the International Classification of Functioning, disability, and health (ICF). This framework has been introduced in 2001 and allows to examine medical, individual, social, and environmental influences on functioning and disability (World Health Organization, 2001). The research of Granberg (2015) resulted in the development of the ICF core set for hearing loss, including the areas of functioning that are most relevant to describe in adults with hearing loss.

The ICF core set for hearing loss is a general framework that can be used to describe the functioning of adults with hearing loss. As stated, formal relationships are a relevant area to describe in this population (Granberg, 2015). More specifically, hearing loss may affect the performance of auditory job tasks. These tasks include speech understanding and detecting, recognizing, and locating sounds (Dreschler & Boermans, 1997; Soli, Giguère, et al., 2018; Tufts et al., 2009). Also, many individuals with hearing loss, tinnitus, or hyperacusis are being hindered by environmental noise at the workplace (World Health Organization, 2011). It is estimated that hearing loss results in difficulties with performing auditory tasks in approximately three percent of the Dutch work force (Sorgdrager, 2015). This percentage is likely to increase, as the society is ageing and the retirement age is being raised.

Participation

Hearing loss may affect several aspects of participation in life situations, including quality of life, communication, interaction with significant others, and work participation (Granberg, 2015; Granberg et al., 2014; Punch et al., 2019). The ICF core set for hearing loss also includes a description of the areas of participation that are relevant for describing the functioning of adults with hearing loss (Granberg, 2015). These areas include private situations with family and friends, such as socializing, community life, sports, arts, culture, religion, and spirituality. Furthermore, work is acknowledged as an important area of participation that is often affected in adults with hearing loss.

With hearing loss, the performance of job tasks can be more challenging. Individuals with hearing loss often attempt to optimize their perception of the sounds of interest by expanding cognitive resources, causing them to experience higher levels of concentration and listening effort (Beechey et al., 2020; McGarrigle et al., 2014). This increased listening effort is related to psychosocial distress and fatigue (Grimby & Ringdahl, 2000). Hearing loss is related to longer and more intense mental and physical fatigue after a day of work. In other words: adults with hearing loss generally experience higher Need For Recovery (NFR) after work compared to normally-hearing adults (Nachtegaal et al., 2009).

It has been shown that the incidence of sick leave due to mental distress is higher in individuals with hearing loss compared to those with normal hearing (Kramer et al., 2006). Also, hearing loss can limit the type or amount of work that can be done, resulting in the feeling of being unable to perform the job sufficiently well (Nachtegaal et al., 2012). Several studies have shown that it is more difficult for individuals with hearing loss to maintain employment (Danermark & Gellerstedt, 2004; Emmett & Francis, 2015; Granberg & Gustafsson, 2021). The level of unemployment is higher in populations with hearing loss and taking earlier retirement is more common in individuals with hearing loss.

Hearing assessment

Several tools and diagnostic instruments can be used to describe, qualify, or quantify the functioning of adults with hearing loss, together capturing all aspects of the ICF framework. Most tools and instruments serve to diagnose a specific aspect of functioning, as will be described below. Additionally, van Leeuwen (2019) developed an ICF-based e-intake tool that can be used in adults with hearing loss. The aim of this tool is to support the identification of problems, personal factors, and environmental factors relevant to the functioning of an individual with hearing loss.

Assessment of anatomy and physiology

The ear can be inspected for abnormalities using otoscopic inspection of the ear (Hogan & Tadi, 2020). A tuning fork can be used to indicate whether the hearing loss is conductive or sensorineural (Isaacson & Vora, 2003). This inspection is often performed by an otolaryngologist. The status of the tympanic membrane and the middle ear can be examined in more detail via tympanometry (Rose, 2011). Additionally, the middle ear muscle reflex can be assessed by measuring the response to a high level acoustic stimulus presented in the ear canal (Schairer et al., 2013).

Assessment of the hearing function

Pure-tone audiometry can be used to assess hearing sensitivity by determining ear specific hearing thresholds at different frequencies (Vogel et al., 2007). Based on this assessment, the degree of hearing loss can be determined (see Table 1). When the degree of higher loss is higher, the difficulties with performing auditory tasks are presumed to be more severe. However, pure-tone audiometry only assesses the ability to detect sounds in a quiet environment and this has been shown to poorly predict other functional hearing abilities (Shub et al., 2020; Tufts et al., 2009). For the medical diagnosis of hearing loss, pure-tone audiometry is necessary, but it does not suffice for the prediction of the consequences of hearing loss on everyday activities.

Table 1. Presumed difficulties based on the severity of the hearing loss

Degree of hearing loss	Pure-tone thresholds	Presumed difficulties with performing auditory tasks
Normal	-10 to 15 dB HL	-
Mild	15 to 35 dB HL	Difficulties with hearing/understanding soft speech, speech at a larger distance, or speech in noisy environments
Moderate	35 to 60 dB HL	Difficulties with hearing/understanding speech at a normal level, even at close distance or in quiet environments. Possible difficulties with making phone calls
Severe	60 to 90 dB HL	Difficulties with understanding loud speech, hearing sirens of emergency cars, hearing industrial sounds, and hearing the sound of a closing door
Profound	>90 dB HL	Speech understanding is impossible based on acoustic information only

This table was derived from the protocol of the Dutch Board for Occupational Medicine (NVAB) ‘hearing loss and tinnitus’ and was translated to English. The pure-tone thresholds represent the average values of the hearing thresholds at 1000, 2000 and 4000 Hz for the better ear.

Assessment of personal and environmental factors

Hearing-related coping behavior

The Communication Profile for the Hearing Impaired (CPHI) has been developed to assess the coping behavior of individuals with hearing loss (Mokkink et al., 2009). The questionnaire distinguishes adequate coping behavior, such as asking for a repeat in case of misunderstanding or good self-acceptance, and inadequate coping behavior, such as avoiding conversations or having feelings of embarrassment as a consequence of communication problems.

Noise

The amount of noise at the workplace can be investigated during noise measurements at the workplace (South, 2013). Another approach for assessing the amount of noise at the workplace is to ask employees to rate the subjective amount of noise at their workplace, a question that is for example included in the Amsterdam Checklist for Hearing and Work (ACHW) .

Other workplace facilitators and barriers can be explored with several scales of the Questionnaire on the Experience and Evaluation of Work (QEEW), such as the scales relationship with colleagues, relationship with supervisor, work pressure, and pace and amount of work (Van Veldhoven et al., 2015).

Assessment of activities and participation

Aspects of activities and participation can be assessed using hearing tests and questionnaires, including generic, hearing specific, work specific, and hearing & work specific questionnaires.

Hearing tests

Speech audiometry assesses the ability to repeat monosyllabic words in a quiet listening environment and can be used to predict the ability to understand speech in a quiet environment (Jerger et al., 1968). It includes monosyllabic words that can be presented in a free field setting or under headphones. Alternative speech stimuli for speech perception tests are digits or everyday sentences, such as the Dutch sentences developed by Plomp and Mimpen (1979), or the VU98 speech material, developed by Versfeld et al. (2000).

Speech perception tests can also be performed in adverse listening conditions, such as in reverberation or in noisy environments. The outcome of these tests is the signal-to-noise ratio (SNR), which is defined as the SNR at which fifty percent of the responses is correct. Some of the speech perception tests in noise can be well used for screening purposes, such as the digits-in-noise test that can be performed without help of an experimenter (Smits et al., 2013) or the Occupational Ear Check (OEC) that can be completed online (Sheikh Rashid & Dreschler, 2018). The stimuli of the digits-in-noise test are sets of three numbers that need to be entered on a computer. The stimuli of the OEC are monosyllabic words that are represented by nine response buttons on the screen with a picture and the written word.

For clinical use, speech perception tests including sentence stimuli are most often used, allowing to predict the ability to understand speech in adverse listening conditions (Plomp & Mimpen, 1979; Versfeld et al., 2000). The presented noise can be either continuous or fluctuating (interrupted). By comparing the outcome of a speech perception test in continuous noise with one performed in fluctuating noise, information is provided on how well an individual is capable of making use of relative silent periods in the noise. In individuals with normal hearing or conductive hearing loss, the outcome of the test in fluctuating noise is expected to be more favorable than the outcome of the test in continuous noise. For individuals with sensorineural hearing loss this is not the case, since they do not profit this much from temporal gaps due to reduced temporal resolution.

To assess the ability of speech understanding of sounds coming from multiple directions, speech perception tests can be performed in a free field condition with separated sound sources. A variety of test conditions has been described, which differ in terms of the number of sound sources, the azimuths at which the sound sources are located, and the type of noise used (Darwin, 2008; Dirks & Wilson, 1969; Gnewikow et al., 2009; Grutters et al., 2007; Ricketts & Henry, 2002; Wagner et al., 2020). The ability to localize sounds can be assessed by asking a test subject to indicate the box where the sound came from (spatial hearing) (Letowski & Letowski, 2012; Santala & Pulkki, 2011; Yost & Brown, 2013). An alternative test to assess the ability to localize sounds is to ask subjects to determine if a sound source is approaching or receding (Andreeva et al., 2018; McCarthy & Olsen, 2017).

Questionnaires

Several generic, health related questionnaires are available, such as the Medical Outcome Study 36-Item Short-Form Health Survey, the EuroQol, and the Health Utilities Index Mark III (Grutters et al., 2007; McHorney et al., 1993). These questionnaires are designed to use in individuals with a wide range of chronic diseases. However, these questionnaires do not recognize communication as a health domain, although communication restrictions are often experienced to be the most important restriction to societal involvement by adults with hearing loss (Granberg, 2015).

Hearing specific questionnaires have also been developed to assess several aspects of participation. The review of Bentler and Kramer (2000) describes 33 hearing specific questionnaires, and even more questionnaires have been developed ever since (Granberg, 2015). The reported prevalence of these questionnaires is low. One of the questionnaires that is internationally used to assess the self-reported hearing ability is the Speech Spatial and Qualities of hearing scale (SSQ) (Gatehouse & Noble, 2004). This questionnaire measures the extent of listening difficulties during several daily life activities.

The burden of hearing loss on work functioning can be assessed with the NFR scale that is included in the QEEW (Van Veldhoven & Broersen, 2003). The score on this scale has been shown to be a predictor of work stress, subjective health problems, and sick leave (De Croon et al., 2003; Sluiter et al., 2003). The NFR scale can therefore also be used for screening purposes.

To our knowledge, there are currently no validated questionnaires measuring aspects participation that are hearing ánd work specific, For Dutch employees, the ACHW is available. Regarding the assessment of participation, this questionnaire includes six questions regarding the subjective listening effort at the workplace, such as the effort it takes to recognize sounds or to communicate in noise.

The role of the occupational physician

Employees with work functioning difficulties can visit an occupational physician. The role of the occupational physician for employees with hearing loss has been described in the protocol of the Dutch Board for Occupational Medicine (NVAB) entitled 'hearing loss and tinnitus'. This protocol has been published in 2020 and states that occupational physicians should explore the difficulties in work functioning that may have been caused by hearing loss.

Occupational physicians screen the hearing function of individuals who visit them with hearing loss complaints if no hearing assessment has been performed recently.

This hearing screening consists of pure-tone audiometry. If the patient suffers from tinnitus, the tinnitus complaints, its onset and progress are inventoried. Further, the consequences of the hearing loss on everyday activities and participation are inventoried through self-report, including the difficulties with performing different auditory tasks and the NFR after work. The occupational physician may ask others their opinion about the consequences of hearing loss at work, such as the supervisor or colleagues.

Personal and environmental factors are also inventoried by the occupational physician through self-report. The personal factors comprise the general health condition, the quality of sleep, psychosocial problems, and the coping strategies that are used. The environmental factors include the auditory work demands, the amount of noise and reverberation at the workplace, other workplace characteristics such as the work pace and the possibility to participate in job decisions, and the social relationships at work.

After formulating the preliminary analysis, occupational physicians can refer to a general practitioner or ENT-specialist for a further assessment of the domain of anatomy and physiology. A referral is sent to an audiological center for further assessment of the other ICF domains, and – if needed – rehabilitation services.

Hearing-critical jobs

In some jobs, the inability to perform auditory tasks may cause a safety risk to the worker, fellow workers, or the general public (Giguere et al., 2008; Tufts et al., 2009). This is for example true in the military, since danger is posed by a soldier that cannot detect and localize sounds made by unseen adversaries in combat. Other workers that perform hearing-critical tasks include those operating vehicles, firefighters, miners, police constables, and law enforcement officers. Most of these jobs need to be performed in noisy workplaces with noise levels above 70 dBA. Here, difficulties with performing auditory tasks may occur, especially in employees with hearing loss (Soli, Giguère, et al., 2018). When hearing loss may result in difficulties with sufficient performance of crucial, auditory job tasks, job-related inclusion and exclusion criteria for employment can be applied to ensure that individual workers can safely and effectively perform hearing-critical job tasks (Soli, Giguère, et al., 2018).

Interventions

Prevention

Hearing loss that is attributed to occupational noise exposure is potentially preventable (Verbeek et al., 2014). Preventive measures have been described in a Cochrane review (Tikka et al., 2017) and in medical guidelines, such as the Dutch multidisciplinary guideline for the prevention of occupational hearing loss (Sorgdrager et al., 2006). It is important to first identify groups at risk of occupational hearing loss. The first group consists of individuals that work in noise of 80 dBA or higher. For this group, a protocol with a hierarchical order of preventive measures has been designed.

Highest in the hierarchical order are measures that reduce or eliminate the source of the workplace noise, by changing materials, processes, or the workplace layout. Second are organizational measures, specifically changing work practices, management policies, or the behavior of workers. Examples are reducing the duration of the noise exposure or reducing the number of employees that is exposed to the noise. Third are measures that intend to increase the use of personal protection devices. Last in the hierarchical order are measures that include monitoring of the hearing levels of exposed workers. Also, it is important that employees at risk for occupational hearing loss receive information and training about the risk of noise exposure. Prevention of hearing loss is an ongoing process, and the efficacy of a prevention program should be evaluated every year.

Based on the European Directive 2003/10/EC, preventive measures that must be undertaken by employers are embedded in the Dutch law. Three exposure limits and corresponding actions are defined:

- Employees exposed to noise levels at or above 80 dBA should receive information and training on the risks of noise exposure, and should have access to hearing protection devices;
- Employees exposed to noise levels above 85 dBA should have access to and use hearing protection devices and have the right to have their hearing checked every four years. Their employers are required to eliminate sound sources whenever reasonable practicable or implement technical or organizational measures to reduce the noise level;

- If the noise level measured at the eardrum exceeds the level of 87 dBA when using hearing protection, direct action is required to reduce the noise level.

Technical interventions

Many technical devices are available to facilitate hearing. These can partially compensate for the listening difficulties that are associated with hearing loss. Conductive hearing loss can often be managed relatively well, but sensorineural and mixed hearing losses are much more difficult to manage (Michels et al., 2019). Fulfilling auditory tasks often remains to require increased attention, concentration, and effort for adults with hearing loss, even if technical devices are used to enhance hearing (Ohlenforst et al., 2017; Shinn-Cunningham & Best, 2008). For example, understanding speech in noise is often more difficult for adults with hearing loss – even when wearing hearing aids – compared to those with normal hearing (Cubick et al., 2018).

Hearing aids

Providing hearing aids is the primary intervention for adults with hearing loss (Hickson et al., 2013; Kochkin, 2009; Timmer et al., 2015). Essentially, hearing aids act to amplify sounds. A microphone detects a sound, which is processed and delivered as an acoustic signal directly into the external ear canal or through a hollow tube (Hampson, 2012). This amplification can be linear or non-linear and is most of the times non-linear (Dillon, 2008). In the case of linear amplification, all sounds of a given frequency are amplified equally irrespective of the level of the signal, or what other sounds are simultaneously present. In case of non-linear amplification, the amplification of a sound may differ between sounds with different sound levels, or when simultaneous sounds are present. To compensate for the reduced dynamic range in ears with sensorineural hearing loss and to reduce the distortion component of hearing loss, non-linear amplification is important.

Earlier in this chapter, we mentioned that the range of levels that can be heard ánd tolerated is often smaller when hearing loss is present. Compression systems in hearing aids aim to adjust the dynamic range of sound levels in the environment to better match with the smaller dynamic range of an individual with hearing loss (Dillon, 2008). When compression is used, the amplification of sounds is automatically adjusted based on the level of the input signal, with higher sound levels receiving more reduced amplification (Levitt, 2001). Compression can improve the intelligibility of soft speech, by increasing the sound level. It can also make loud sounds more comfortable, by decreasing the sound level. A disadvantage of compression is that it may increase the level of soft background noise.

Hearing aids are able to reduce the effects of noise to some degree (Brons et al., 2013; van den Tillaart-Haverkate et al., 2017). The aim of noise reduction programs in hearing aids is to increase listening comfort in noisy environments by amplifying the speech signal more than the noise. Therefore, the program needs to recognize and analyze the speech and noise separately which can be accomplished since the spectrum of noise differs from the spectrum of speech.

In modern hearing aids, directional microphones are used. These microphones are more sensitive to sounds coming frontally than to sounds coming from other directions (Dillon, 2008). Especially in noisy environments with a close, frontal talker, the use of directional microphones can improve speech understanding (Boymans et al., 2008). Disadvantages of directional microphones can be that wanted sounds from other directions may receive insufficient amplifications and that increased internal noise can be experienced in quiet places. Also, a directional microphone is only effective for sounds that are relatively close to the person who is wearing the hearing aids.

Many hearing aid features, such as compression or directionality, are useful in some, but not in all situations. The hearing aid fitting can be optimized by using multiple hearing aid programs that are tailored to specific situations. This allows for optimizing the hearing aid settings for different situations, such as situations with or without background noise.

Alternative devices

The aim of alternative listening devices is to improve hearing and communication outcomes in individuals with hearing loss by amplifying sounds (Maidment et al., 2016; Maidment et al., 2018). These devices can be either stand-alone products that amplify sounds – such as smartphone hearing aid applications – or assistive listening devices that provide additional features to conventional hearing aids. For example, an external microphone or a table microphone may facilitate speech understanding during meetings and wireless products may enhance making a phone call by connecting the hearing aid to a mobile phone. Maidment et al. (2018) conducted a systematic review and meta-analysis on the efficacy of additional listening devices. Their evidence suggests that the outcome of speech perception tests in noise improve when alternative devices are used compared to using only hearing aids or no other technical devices. However, there was no robust evidence that self-reported outcome measures also improve, including listening effort and quality of life.

Hearing protectors

Hearing protectors can be used to attenuate loud sounds. A first distinction can be made between ear muffs and earplugs. Ear muffs are rigid cups that completely cover the external ears (Rice & Coles, 1966). They are held in place by an adjustable headband or can be mounted in a helmet. Earplugs are often made of rubber or plastic and are designed to insert into the ear canal. Earplugs can be either disposable, generic (pre-molded), or custom-molded.

A second distinction can be made between hearing protectors that provide passive versus active protection. Most hearing protectors provide passive protection. In this type of protectors, the attenuation is provided independently from the level of the sound. Passive hearing protectors have no electrical or digital components in them. Contrarily, in active hearing protectors, the attenuation depends on the level of the sound. Active hearing protectors have mechanical, electrical, or digital components in them. Some active hearing protectors can also provide extra noise reduction by offering a soft sound that is exactly the opposite of the sound wave of the noise. Lastly, some active hearing protectors can be used to communicate with – for example the office headset – or to play music.

Hearing protectors attenuate sounds on average with 20 dBA (Brennan-Jones et al., 2020), but have the disadvantage of being uncomfortable to wear, especially when they are worn for a long duration. Another disadvantage of hearing protectors for individuals with hearing loss is that they may even further complicate the performance of auditory tasks (Morata et al., 2005; Smalt et al., 2020).

Additional rehabilitation strategies

Since technical interventions cannot fully compensate for all consequences of hearing loss, there is often a need for additional rehabilitation strategies (Cox, 2005).

The framework of aural rehabilitation is therefore increasingly applied in audiology (Ferguson et al., 2019). The aim of aural rehabilitation is to reduce the difficulties of individuals with hearing loss in daily life functioning, including difficulties in work participation. This can be achieved by the provision of technical interventions, but aural rehabilitation also includes three other components – perceptual training, instruction, and counselling – that may contribute to the reduction of difficulties with performing everyday tasks of societal involvement (Boothroyd, 2007, 2017).

The four components of aural rehabilitation can be provided separately or in combination. Perceptual training includes training of speech reading or auditory skills. The rationale is that speech perception performance can improve when hearing impaired individuals extract more information from the speech signal or the context. Instruction mainly focusses on how technical devices can be used properly and may include demonstrating or coaching. The focus of counselling is to help with developing effective coping behavior.

Aural rehabilitation can be provided in different forms (Boothroyd, 2010). It may consist of individual training, which has the advantage that it can be tailored specifically to individual needs. However, the variation of inputs – different voices, experiences of others – is small during individual training. Alternatively, aural rehabilitation can consist of group training with a clinician, which has the advantage that the participants might benefit from the interactions with their peers. In the Netherlands, group training involving aural rehabilitation is often referred to as a communication course. These communication courses are offered by several university medical centers and audiological centers, and consist of approximately ten to twelve sessions that include speech reading training, instruction, and counselling.

Occupational health interventions

The protocol of the Dutch Board for Occupational Medicine (NVAB) 'hearing loss and tinnitus' provides a framework for occupational physicians on the interventions that can be provided to individuals with work functioning difficulties caused by hearing loss.

Several interventions have been suggested regarding external factors. Firstly, occupational physicians can investigate what measures could optimize the acoustic environment of the workplace. For example, environmental noise can be reduced by removing technical devices that produce noise – such as the printer – from the workplace and room reverberation can be reduced with absorbent surfaces. Also, changing the sound of the telephone, or the sound of safety alarm systems can make them more audible. Secondly, organizational changes can be suggested to facilitate work functioning, such as working from home more often, taking more breaks, or spreading out meetings over the day. Lastly, providing information to the supervisor or colleagues can stimulate them to be more understanding and supportive. If technical interventions, aural rehabilitation, and occupational health interventions insufficiently enable job performance, changing work can be considered.

Regarding the personal factors, providing information is suggested to be an important intervention for occupational physicians to provide. This includes information on hearing loss, the possible consequences of hearing loss for work functioning, options for technical interventions, communication strategies to use with colleagues, and websites where more information is provided. Additionally, the occupational physician can provide information on the possibilities for aural rehabilitation. Occupational physicians can send a referral for the interventions of interest. For example, the employee can be referred to an audiological center to start with a communication course, to a speech therapist for a training in speech reading, or to a social worker or psychologist for personal coaching.

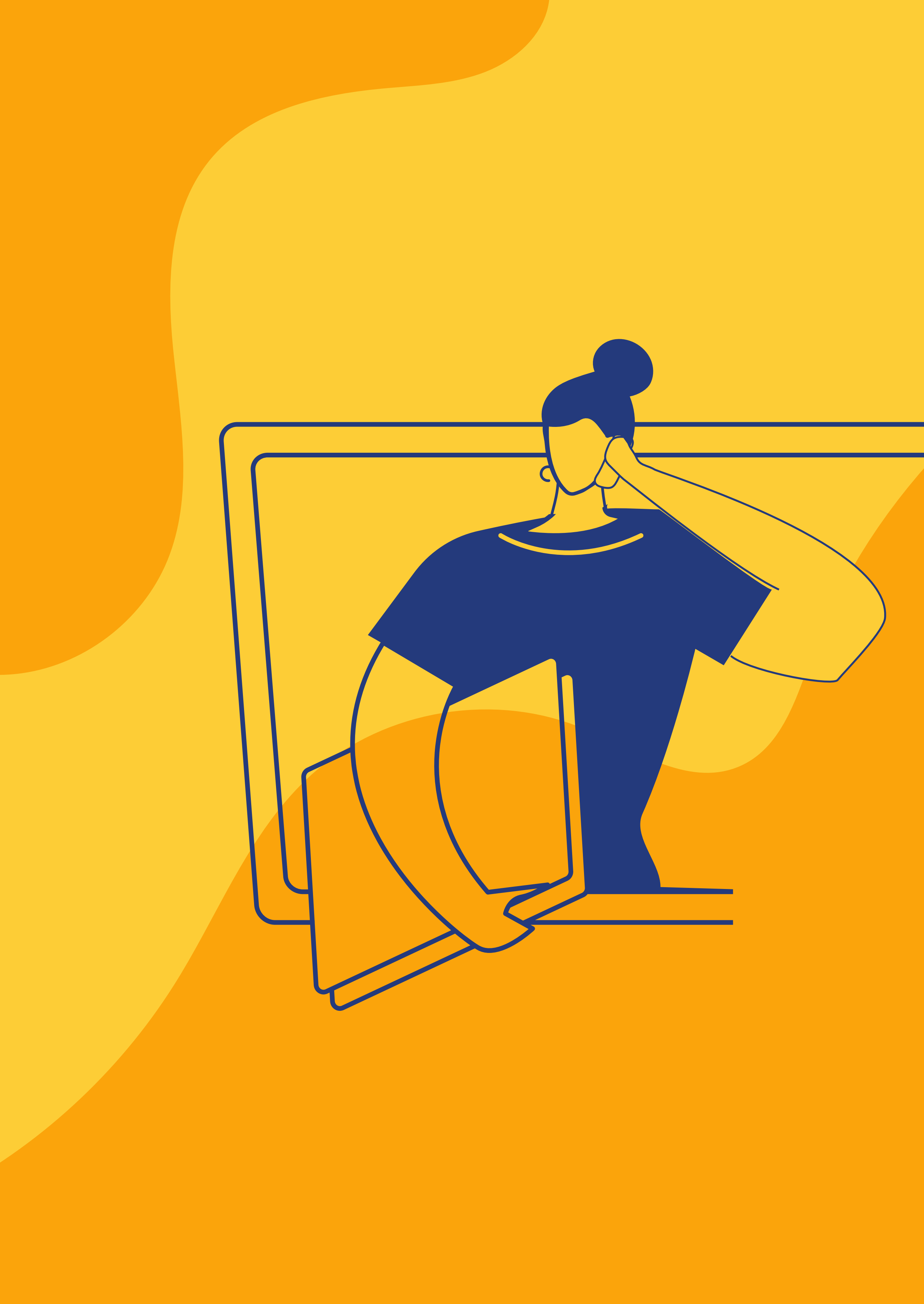
Outline of the thesis

This thesis covers several aspects of professional functioning in employees with hearing loss. The following research aims are addressed:

- To explore what hearing-related, personal, and environmental factors influence the difficulties of employees with hearing loss and how these factors interfere with each other;
- To evaluate the effect of current rehabilitation practices measured with tools that are currently used in audiological practice;
- To evaluate tests that can be used to assess the performance of hearing-critical job tasks and to describe the development of a new tool to evaluate the ability to detect auditory warning signals.

Part I

Factors influencing professional functioning



Chapter 1

Factors influencing the need for recovery in employees with hearing loss: a cross-sectional study of health administrative data

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Abstract

Objective

Need for recovery is a predictor of work stress and health problems, but its underlying factors are not yet well understood. We aimed to identify hearing-related, work-related, and personal factors influencing need for recovery in hearing-impaired employees.

Methods

We retrospectively identified hearing-impaired employees (N = 294) that were referred to the Amsterdam University Medical Center between 2004 and 2019. Routinely obtained healthcare data were used, including a survey and hearing assessments. A directed acyclic graph was constructed, revealing the hypothesized structure of factors influencing need for recovery as well as the minimal set of factors needed for multiple regression analysis.

Results

Four variables were included in the regression analysis. In total, 46.1 percent of the variance in need for recovery was explained by the factors 'feeling that something should change at work' ($B = 19.01$, $p < 0.001$), subjective listening effort ($B = 1.84$, $p < 0.001$), personal adjustments scale score ($B = -0.34$, $p < .001$), and having a moderate/poor general health condition ($B = 20.06$, $p < 0.001$). Although degree of hearing loss was associated with subjective listening effort, the direct association between degree of hearing loss and need for recovery was not significant.

Conclusions

The results suggest that the way employees perceive their hearing loss and how they cope with it directly influence need for recovery, rather than their measured degree of hearing loss. Additionally, general health condition was found to be an independent factor for need for recovery. The results should be confirmed by future, longitudinal research.

Introduction

Hearing loss is a common occupational malady (Backenroth-Ohsako et al., 2003; May, 2000). Prevalence estimates vary from 7 to 31 percent and increase with age and exposure to noise (Hasson et al., 2010; Masterson et al., 2016; May, 2000; Nelson et al., 2005). It is estimated that 3 percent of the Dutch work force experiences difficulties in their job due to their hearing loss (Sorgdrager, 2015). These difficulties often result in greater levels of fatigue, fear, social isolation, and psychophysiological stress, caused by the fact that hearing loss goes along with increased listening effort during activities, such as communicating in background noise or localizing sounds (Hornsby & Kipp, 2016; Kramer et al., 2006; Morata et al., 2005; Ohlenforst et al., 2017; Svinndal et al., 2018). Adverse implications for work are sick leave due to mental distress, unemployment, and earlier retirement (Danermark & Gellerstedt, 2004; Hasson et al., 2011; Kramer et al., 2006; Punch, 2016). The degree of hearing loss is significantly associated with need for recovery (NFR) (Nachtegaal et al., 2009), a measure that can contribute to early identification of occupational diseases (De Croon et al., 2003; Moriguchi et al., 2010; Sluiter et al., 2003; Sluiter, 1999).

NFR has been defined as the need to recuperate from work- induced fatigue, primarily experienced after a day of work (Jansen et al., 2002; Van Veldhoven & Broersen, 2003). The degree of NFR is determined by the intensity of mental and physical work-induced fatigue and by the period required to return to a normal level of functioning. NFR can be measured with the validated Questionnaire on the Experience and Evaluation of Work (QEEW), which includes 11 dichotomous statements, such as 'I find it hard to relax at the end of a working day' and 'When I get home, people should leave me alone for some time' (Van Veldhoven & Broersen, 2003). NFR is a predictor of work stress, subjective health problems, and sick leave (De Croon et al., 2003; Sluiter et al., 2003). In line with the International Classification of Functioning, Disability and Health (ICF) (Organization, 2001), NFR has been described to be a complex construct that is influenced by disease specific, personal, and environmental factors (Gommans et al., 2015).

Despite the importance of the outcome NFR both from health and economic perspectives, the studies examining NFR in patients with hearing loss are scarce. To our knowledge, three studies have been reported so far. In the cross-sectional study by Nachtegaal et al. (2009), the relationship between NFR and hearing status was examined in 925 normally-hearing and hearing-impaired working adults. NFR was assessed with the QEEW and hearing status with the national hearing test (Smits et al., 2006), a speech-in-noise test that was performed over the internet. Their regression analysis showed that poorer hearing was significantly associated with higher NFR. In the cross-sectional study by Juul Jensen et al. (2018), the relationship between NFR and tinnitus was examined in 32 hearing aid users of which 16 were suffering from tinnitus. NFR was assessed with a Danish translation of the QEEW and tinnitus with the Tinnitus Handicap Inventory. The authors reported that the degree of tinnitus severity was significantly associated with higher NFR. Finally, a randomized controlled trial has been reported by Gussenhoven et al. (2017) in a population of 136 hearing-impaired employees. The study evaluated the effectiveness of a vocational enablement protocol on NFR as compared to usual care for hearing-impaired employees. This protocol is a multidisciplinary program of care that consists of vocational and audiological components, such as an intake interview conducted by the psychologist or social worker and clinical occupational physician, the performance of pure-tone audiometry and a speech-in-noise test, and a multidisciplinary team meeting in which the technical, speech therapeutic, and psychosocial intervention options are discussed (Gussenhoven et al., 2012). The intervention of the control group consisted of any kind of another audiological revalidation. NFR had not significantly changed after 12 months follow-up, and there were no significant differences between the intervention and the control group (Gussenhoven et al., 2017). The authors concluded that NFR may not adequately capture what is covered in the vocational enablement protocol. However, it is unclear how many employees received technical, speech therapeutic, and psychosocial interventions and thus which interventions did not influence NFR. Further, because the factors influencing NFR in hearing-impaired employees are not yet well understood, it is difficult to indicate which changes in degree of hearing loss could have an effect on NFR.

Multiple studies have indicated work characteristics influencing NFR, such as the number of working hours (Jansen et al., 2002; Verdonk et al., 2010), lack of participation in work decisions (Van Veldhoven & Broersen, 2003), and problems in the relationship with colleagues (Kiss et al., 2008; Van Veldhoven & Broersen, 2003). High job demands and low job support are associated with high NFR and mixed results are presented for job control (Kiss et al., 2008; Kraaijeveld et al., 2014; Sluiter et al., 2001; Sonnentag & Zijlstra, 2006; Van der Hulst et al., 2006). Job demands and job control have also been demonstrated to be associated with NFR in hearing-impaired employees, independently of the degree of hearing loss measured with an online hearing test (Nachtegaal et al., 2009). To our knowledge, further studies examining the effect of work characteristics on NFR in hearing-impaired employees are lacking, but high auditory work demands were shown to be related to sick leave due to stress-related complaints (Kramer et al., 2006).

Personal characteristics influencing NFR in the general working population include gender (Kiss et al., 2008), age (Gommans et al., 2015; Kiss et al., 2008), general health condition (Gommans et al., 2015; Van der Starre et al., 2013), educational level (De Croon et al., 2003), and coping style (De Vries et al., 2015; Machin & Hoare, 2008). Several studies have indicated that people with hearing loss use coping strategies in their interaction with others (Backenroth-Ohsako et al., 2003; Barker et al., 2017; Hallberg & Carlsson, 1991). Also, the Communication Profile for the Hearing Impaired (CPHI) has been developed to investigate how people cope with their hearing loss (Mokkink et al., 2010). This questionnaire contains questions on the communication strategies and non-verbal strategies that are commonly used by people with hearing loss. However, the influence of hearing loss coping on NFR has not yet been examined.

The evidence on factors influencing NFR in hearing-impaired employees lags behind, although the outcome NFR has potential for early identification of hearing-impaired employees being at risk for occupational diseases, and may be a valuable tool for evaluating the effects of interventions aiming to prevent these problems. It is hypothesized that hearing loss, work characteristics, and personal characteristics influence both each other and NFR. Because earlier studies do not provide a framework on how these factors interfere, NFR may not be optimally understood in employees with hearing loss. The primary aim of this study is therefore to identify hearing-related, work-related, and personal factors influencing NFR in hearing-impaired employees. To examine if the influence of hearing-related, work-related, and personal factors on NFR differs from their influence on listening effort, which is a more commonly assessed construct when assessing the functional disability of hearing-impaired employees, the secondary aim is to identify factors influencing listening effort.

Methods

Design

We performed a single center study with an observational and cross-sectional design at the Amsterdam University Medical Center (UMC). Factors potentially influencing NFR were derived from hearing assessments performed at the hospital and a hearing survey that was completed at home. All variables were derived from patient files.

Participants

We retrospectively identified patients referred to Amsterdam UMC's ENT-Audiology department (location AMC) by their occupational physician. All patients were thus referred from occupational healthcare. Eligible patients visited the hospital between 2004 and 2019, were aged between 18 and 67, underwent pure-tone and speech audiometry, and completed the hearing survey prior to their hospital visit. Patients were included regardless of the cause of their hearing loss. For patients with multiple referrals, the data were included belonging to the first referral with a completed questionnaire and hearing evaluation. To prevent bias, patients were excluded if they were referred to the hospital for a fitness for job assessment by their employer. The reason is that hearing loss complaints might be experienced or reported differently if continuation of the job depends on it. All patients received a letter with information about the study. Because of the retrospective study design, an opt-out procedure was performed.

A total of 646 patients were identified of being referred to the ENT-Audiology department by their occupational physician (Figure 1). Patients referred to the department to determine fitness for their job ($n = 283$) were not eligible for the study, as were patients older than 67 ($n = 2$). Further, patients were excluded that declined to participate ($n = 6$) or had an incomplete patient file, specifically missing pure-tone audiometry ($n = 4$), missing survey ($n = 20$), or incomplete survey ($n = 37$).

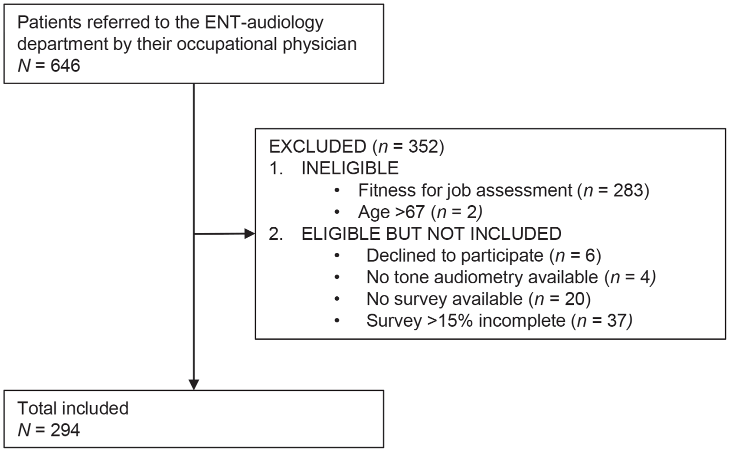


Figure 1. Flowchart

Data collection

The data were collected retrospectively by review of patient files. Outcomes of the hearing survey and the hearing assessments were entered into Castor, an electronic database (Castor, 2019). by the author and a research assistant. Data entry was checked in a sample of 50 percent of the cases. Information not available in patient files were noted as missing.

Hearing assessment

The hearing assessments consisted of unaided pure-tone and speech audiometry for all patients. At the ENT-Audiology Department, speech reception tests in noise are not routinely performed in all patients, but only if understanding speech in a noisy environment is important for job performance. Therefore, speech reception tests in noise were performed depending on the profession and the associated auditory demands.

Pure-tone and speech audiometry

Pure-tone and speech audiometry (ISO 8253–1, 1989) were performed in a sound-isolated booth using calibrated clinical audiometers (AC40 and Decos audioNigma) and TDH 39 headphones. According to the hospital protocol, pure-tone thresholds for air and bone conduction were reported in decibel (dB) hearing level (HL) at frequencies 250 Hz, 500 Hz, 1000 Hz, 2000 Hz, 4000 Hz, and 8000 Hz, with adequate masking (if necessary). For a healthy, normally-hearing individual, hearing thresholds up to 25 dB HL are regarded as normal (Martin & Champlin, 2000). According to the American Academy of Otolaryngology, Binaural Hearing Impairment (BHI) was calculated from the mean of pure-tone thresholds for air conduction at 1000 Hz, 2000 Hz, and 4000 Hz and a 5:1 weighting favoring the better (American Academy of Otolaryngology, 1979). BHI provides a valid estimation of the hearing disability that a person with a degree of hearing loss would experience (Dobie, 2011). Speech audiometry was performed with the standard Dutch CVC word lists (Bosman & Smoorenburg, 1995) and was used to calculate the percentage of maximum speech recognition for the better ear. It has been recommended to transform percentages of maximum speech recognition, to enhance the normality of the data for the statistical analysis (Sherbecoe & Studebaker, 2004). Therefore, we transformed the percentages of maximum speech recognition using the rationalized arcsine formula.

Speech reception threshold test

Speech reception in continuous noise was assessed in a free field setting (S0N0) using everyday Dutch sentences developed by Plomp and Mimpen (1979) or the sentences developed by (Versfeld et al., 2000). These sentence materials have been shown to result in similar test outcomes (Versfeld et al., 2000). The aim of performing a speech reception test in noise is to objectify the influence of the hearing loss on functional speech understanding at the workplace. Therefore, all patients were asked if they wear hearing aids at work. If they did, the critical Signal-to-Noise Ratio (SNR) was measured for aided conditions. If they did not, the SNR was measured for the unaided conditions. We have combined the SNR outcomes of patients who performed the test with and without hearing aids. We will refer to these measurements as speech in noise tests performed in patient's daily work situation. For a healthy, normally-hearing individual, an SNR below − 4 can be expected (Versfeld et al., 2000).

Survey

Prior to the hospital visit, patients completed an extensive hearing survey to investigate personal and environmental factors that potentially influence NFR. This survey consisted of three questionnaires and additional questions.

Questionnaire on the Experience and Evaluation of Work

Three scale scores were derived from the QEEW, a generic questionnaire on psychosocial workload and work stress (Van Veldhoven et al., 2002). The sum score of each QEEW scale can be converted to a scale score ranging from 0 to 100. A higher score represents a higher level of the working condition. First, the primary outcome was operationalized with the NFR scale score that is composed of 11 items, such as 'I find it hard to relax at the end of a working day'. An NFR scale score higher than 54 indicates an increased risk for occupational and health problems (Broersen et al., 2004). Second, the score on the scale participation at work was included as a work-related factor. This scale consists of 8 items, such as 'Can you participate in decisions about the nature of your work?'. Third, the score on the scale collegial support was included as a work-related factor. This scale consists of 9 items, such as 'If necessary, can you ask your colleagues for help?' The QEEW has been shown to be reliable with good internal consistency and multiple studies have concluded good validity (Van Veldhoven et al., 2002; Van Veldhoven et al., 2015; Van Veldhoven & Sluiter, 2009). For example, the NFR scale has been shown to have good content-, construct-, and criterion-related validity in relation to work-related health.

Amsterdam Checklist for Hearing and Work

A 4-point response scale was used to inventory the occurrence of six hearing-related job activities, specifically detecting sounds, distinguishing sounds, communication in quiet, communication in noise, localizing sounds, and exposure to loud sounds. These questions on the occurrence of hearing- related job activities were merged into a value representing auditory work demands by calculating a weighted sum score. Communication in quiet and distinguishing sounds are considered to be the easiest hearing activities and received a weighting of 1. Detecting and localizing sounds are considered to be of moderate difficulty and received a weighting of 2. Exposure to loud sounds and communication in noise are considered to be the most difficult and received a weighting of 3. This score can range between 0 and 48.

We did not only investigate the occurrence of the six hearing-related job activities, but also the effort they take. Since these six additional questions on the effort of hearing have good internal consistency ($\alpha = 0.81$), we have calculated a sum score of these six items, further considered as subjective listening effort (LE). This score can range between 0 and 18.

Other questions derived from the Amsterdam Checklist for Hearing and Work (ACHW) include the number of working hours a week (scale value) and fulfilling managerial tasks (dichotomous). All patients were asked whether they fulfilled managerial tasks, because managerial activities can be embedded in many professions and require specific skills that might appeal to hearing acuity, such as organizational and social skills (Whitley, 2019).

Communication Profile for the Hearing Impaired

To investigate the coping strategies, the CPHI was used. The CPHI aims to distinguish between adequate and inadequate coping behavior (Mokkink et al., 2009). It has been translated and validated for Dutch and contains two domains. The first domain regards communication strategies and contains 8 items for maladaptive behavior, 8 items for verbal strategies, and 7 items for nonverbal strategies. For example, items within the domain of communication strategies are 'I avoid conversations, because of my hearing loss' (maladaptive behavior), 'When I don't understand what is being said, I ask for a repeat' (verbal strategies), and 'I always try to watch a person's face' (non-verbal strategies). The second domain regards personal adjustments (PA) and contains 6 items for self-acceptance, 8 items for acceptance of loss, and 15 items for stress and withdrawal. For example, items within the domain of PA are 'I get mad at myself when I can't understand others' (self-acceptance), 'I can't talk to people about hearing loss' (acceptance of loss), and 'I get tense, because of my hearing loss' (stress and withdrawal). The CPHI scales are scored such that low scores are indicative of communicative of adjustment difficulties.

Additional survey questions

Additional questions included the personal characteristics age, gender, educational level, and general health condition. For health condition, the response options were good, moderate, and bad. We used a dichotomous question to ask if the employees were feeling that something should change in their work situation. Two hearing-related characteristics were inventoried with a dichotomous question, specifically the presence of tinnitus, and the use of hearing aids.

Variables in the analysis

A total of 17 factors potentially influencing NFR were explored for eligibility in the statistical model (Table 1). The same factors were explored for the secondary analysis.

Hearing-related factors consisted of LE, BHI, the maximum speech discrimination score, the critical SNR measured in the speech-in-noise test, and the presence of tinnitus. Work- related factors consisted of work participation, collegial support, auditory work demands, fulfilling managerial tasks, the number of working hours a week, and 'feeling that something should change at work'. Personal factors consisted of the communication strategies and PA used, and general health condition. In addition, age, gender, and educational level were considered to be potential confounders.

Table 1. Factors hypothesized to influence the need for recovery

	Derived from	Operationalization
Binaural Hearing Impairment	Pure-tone audiometry	Sum of pure-tone thresholds at 1, 2 and 4 kHz with a 5:1 weighting favoring the better ear
Maximum discrimination	Speech audiometry	Percentage of maximum speech recognition for the better ear
SNR in continuous noise	Speech recognition test	SNR measured in the daily life situation at work (with or without hearing aids)
Presence of tinnitus	Survey4	Item score (dichotomous)
Work participation	Survey (QEEW)	Standardized scale score
Collegial support	Survey (QEEW)	Standardized scale score
Subjective listening effort	Survey (ACHW)	Sum score of 6 questions (4-point scale) on experienced listening effort during hearing-related job activities
Auditory work demands	Survey (ACHW)	Weighted sum score of 6 questions (4-point scale) on the occurrence of hearing-related job activities
Fulfilling managerial tasks	Survey (ACHW)	Item score (dichotomous)
Number of working hours	Survey (ACHW)	Item score (open question)
Feeling something should change	Survey	Item score (dichotomous)
Communication strategies	Survey (CPHI)	Standardized scale score consisting of maladaptive behavior, verbal strategies and non-verbal strategies
Personal adjustments	Survey (CPHI)	Standardized scale score consisting of self-acceptance, acceptance of loss and stress and withdrawal
Age	Survey	Item score (open question)
Gender	Survey	Item score (dichotomous)
General health condition	Survey	Item score (dichotomized)
Educational level	Survey	Item score (6 categories)

SNR indicates Signal-to-noise ratio; QEEW, Questionnaire on the Experience and Evaluation of Work; ACHW, Amsterdam Checklist for Hearing and Work (ACHW); CPHI, Communication Profile for the Hearing Impaired.

Statistical analysis

Distributions of all variables were examined. For continuous variables, the means and standard deviations were calculated and histograms were used to check normality. For categorical variables, proportions were calculated. We drew a directed acyclic graph to reduce the required sample size and prevent power issues without missing factors related to the outcome measure and without missing factors required to reduce bias. This method aims to assist in the selection of appropriate variables for the regression analysis, as is recommended by Greenland et al. (1999). Afterwards, multiple linear regression was performed.

Directed acyclic graph

We visualized our hypothesized relationships between the factors and their association with the primary outcome NFR and secondary outcome LE. To simplify the graph, we examined the correlations between the factors in the graph and removed all negligible associations, defined as correlation coefficients between − 0.3 and + 0.3 (Hinkle et al., 2003). Pearson correlation coefficients were used to examine the correlations between continuous variables, Phi correlation coefficients for dichotomous variables, and Bi-serial correlation coefficients to determine the correlation between a dichotomous and a continuous variable (Akoglu, 2018; Kraemer, 2014). Further simplification was accomplished by following the method of Shrier and Platt (2008), including removal of all factors that were not directly or indirectly related to neither the primary nor the secondary outcome.

Multiple imputation

Multiple imputation was used to impute factors directly or indirectly related to the primary or secondary outcome (Pedersen et al., 2017). The number of imputations was ten, thus ten imputed datasets were created. The imputation model consisted of all variables included in the conceptual model (Table 1).

Linear regression analysis

Linear regression with a forward stepwise selection method ($\alpha = 0.05$) was manually performed with all variables directly related to NFR. As a result of the strategy used to select factors for the analysis, the model was unadjusted for other factors. We checked for interaction effects with the use of hearing aids or not with all variables in the analysis, because the relationship between objective and subjective factors might be different for employees that wear hearing aids. If an interaction term was not found to be significant ($p > 0.05$), it was removed. Data organization and statistical analysis were performed using the Statistical Package for Social Sciences (SPSS) version 25.0 (Armonk New York USA). The critical value of significance was 0.05 for all statistical analyses.

Results

Participants

A total of 294 patients, mean age 56 (SD 8.9), were included the study (Table 2). Patients reported being in good health (60.2%), moderate/poor health (39.1%), and poor health (0.7%). Since 0.7% of the cases used the third category, this question was dichotomized for the statistical analysis. The mean BHI was 41.3 dB HL (SD 20.76). For the maximum speech discrimination score in quiet, the median was 100% (range 15%–100%). The mean critical SNR was -2 dB (SD 4.4). Hearing aids were used by 58.5% of the patients.

All educational levels were represented. The most common professions were teacher (26.6%), administrative job (19.4%), doctor/nurse (10.2%), and managerial jobs (9.2%). Many patients with and without managerial jobs reported to fulfil managerial tasks (88.4%). The mean number of working hours per week was 33.6 (SD 8.7). The mean score for NFR was 54.94 (SD 34.12). In 55.8% of the participants, the NFR score was above 54, indicating an increased risk for occupational and health problems (Broersen et al., 2004). The mean LE was 10.28 (SD 4.05). The CPHI resulted in a mean score of 79.79 (SD 15.84) for communication strategies and 97.31 (SD 26.23) for PA. A normal distribution was confirmed for all variables, except for the percentage of maximum speech recognition. Even after application of the rationalized arcsine transformation (Sherbecoe & Studebaker, 2004), the variable remained skewed to the right. This variable was therefore not used in the analysis.

Table 2. Characteristics of the included participants ($N = 294$)

	%	Mean (SD)	Min ; max	Missing *n*
Age		50.9 (8.9)	19 ; 65	0
Gender (% male)	58.6			0
General health condition				2
Good	60.2			
Moderate/poor	39.1			
Degree of hearing loss (weighted)				0
Normal hearing (<15 dB HL)	22.9			
Mild (25-40 dB HL)	28.0			
Moderate (40-60 dB HL)	31.7			
Severe (60-80 dB HL)	11.3			
Profound (>80 dB HL)	6.1			
Binaural hearing impairment[a]		41.3 (20.8)	3.8 ; 110.8	0
Maximum discrimination		94.5 (12.9)	15 ; 100	1
SNR in continuous noise		-2.2 (4.4)	-9 ; 14.6	158
Presence of tinnitus (% yes)	63.9			4
Hearing aids (% yes)	57.5			3
Educational level				5
Primary/lower vocational	7.6			
General intermediate	7.6			
Intermediate vocational	22.5			
General secondary	10.0			
Higher vocational	36.0			
University	16.3			
Profession				1
Teacher	26.6			
Administrative	19.5			
Doctor/nurse	10.2			
Manager	9.2			
Coach/social worker	5.5			
Construction worker	4.4			
Police officer/fireman	3.4			
Other	21.2			
Number of working hours		33.6 (8.7)	16 ; 48	1
Fulfilling managerial tasks (% yes)	88.4			21
Need for recovery (range 0-100)		54.9 (34.1)	0 ; 100	12
Work participation (range 0-100)		49.0 (22.8)	0 ; 95.83	11
Collegial support (range 0-100)		20.8 (13.2)	0 ; 55.56	14
Subjective listening effort (range 0-18)		10.3 (4.1)	0 ; 18	20
Auditory work demands (range 0-48)		30.6 (6.1)	16 ; 48	10
Feeling something should change (% yes)	45.2			24
Communication strategies (range 23-115)		79.8 (15.8)	0 ; 115	7
Personal adjustments (range 29-145)		97.3 (26.2)	0 ; 145	7

SNR indicates Signal-to-Noise ratio.
[a] Binaural hearing impairment is defined as the mean of the pure-tone averages of the left and right ear with a 5:1 weighting favoring the better ear.

Directed acyclic graph

The presence of tinnitus, age, and the educational level were not directly or indirectly associated with NFR and LE. Consequently, these factors were not included in the directed acyclic graph. Figure 2 shows the directed acyclic graph that was constructed. Four variables directly influenced the primary outcome NFR, specifically 'feeling that something should change at work' (r = 0.476), LE (r = 0.527), PA (r = − 0.456), and general health condition (r = 0.453). Two of these variables did also directly influence the secondary outcome measure LE, respectively, 'feeling that something should change at work' (r = .390) and PA (r = -.442). LE was also directly influenced by BHI (r = .318) and auditory work demands (r = .413). The hearing assessment outcomes did not significantly correlate with NFR, including BHI (r = .096, p = .109), maximum discrimination score (r = .010, p = .873), and SNR (r = .060, p = .492). All correlations between the hypothesized factors and the primary and secondary outcome are shown in Table 3.

Table 3. Correlations between the hypothesized factors and the primary outcome need for recovery and the secondary outcome subjective listening effort.

	Need for recovery	**Subjective listening effort**
Binaural hearing impairment	.099	.318
Maximum discrimination	-.024	-.167
SNR in continuous noise	.060	.203
Presence of tinnitus	.102	.094
Work participation	.154	.006
Collegial support	.198	.130
Subjective listening effort	.527	-
Auditory work demands	.226	.413
Fulfilling managerial tasks	-.050	.109
Number of working hours	-.152	-.071
Feeling something should change	.476	.390
Communication strategies	.032	.197
Personal adjustments	-.456	-.442
Age	-.018	.133
Gender	-.186	-.133
General health condition	.453	.289
Educational level	.108	.124

SNR indicates Signal-to-Noise Ratio.

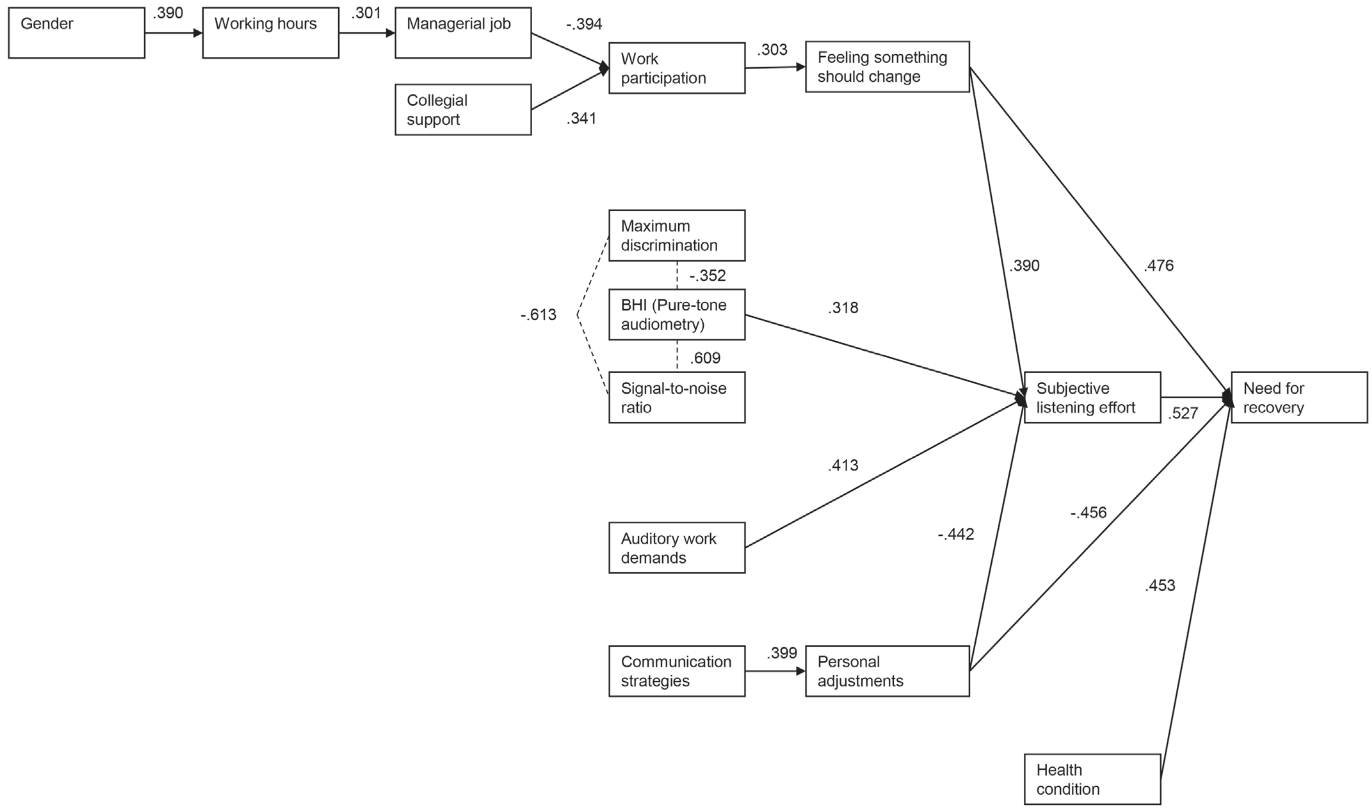


Figure 2. Directed acyclic graph: a visualization of our hypothesized relationships between the factors and need for recovery, simplified by removing all correlations between – 0.3 and + 0.3, followed by simplification according to the method of Shrier and Platt (2008). SNR indicates Signal-to-Noise Ratio.

Multiple regression analysis

The results of the primary regression analysis (Table 4) indicated that the four predictors explained 46.1 percent of the variance ($p < .001$) of the NFR. 'Feeling that something should change at work', LE, the PA scale score, and having a moderate/poor general health condition were significantly related to higher NFR. In the secondary regression analysis (Table 5), four predictors explained 43.1 percent of the variance ($p < .01$) of LE. 'Feeling that something should change at work', BHI, auditory work demands, and the PA scale score were significantly related to LE. In both analyses, there were no significant interaction effects.

Table 4. Results of multiple linear regression analysis of factors associated with *need for recovery*

	Variable	B	95% CI	p
Complete case analysis R^2=.495	Constant	32.03	9.12 ; 54.93	.006
	Feeling something should change[a]	19.01	12.04 ; 25.97	<.001
	Subjective listening effort	1.84	0.88 ; 2.81	<.001
	Personal adjustments	-0.34	-0.49 ; -0.19	<.001
	General health condition[b]	20.06	13.18 ; 26.94	<.001
Pooled analysis after imputation R^2=.461	Constant	31.78	8.70 ; 54.86	.010
	Feeling something should change[a]	17.88	10.48 ; 25.29	<.001
	Subjective listening effort	1.93	0.97 ; 2.88	<.001
	Personal adjustments	-0.31	-0.45 ; -0.16	<.001
	General health condition[b]	17.99	11.44 ; 24.53	<.001

[a] Reference category = not feeling that something should change in the work situation.
[b] Reference category = being in good health.

Table 5. Results of multiple linear regression analysis of factors associated with *subjective listening effort*

	Variable	B	95% CI	p
Complete case analysis R^2=.408	Constant	6.78	3.77 ; 9.80	<.001
	Feeling something should change[a]	1.96	1.12 ; 2.80	<.001
	Binaural hearing loss	0.01	0.01 ; 0.02	<.001
	Auditory work demands	0.19	0.12 ; 0.26	<.001
	Personal adjustments	-0.05	-0.06 ; -0.03	<.001
Pooled analysis after imputation R^2=.431	Constant	6.10	3.35 ; 8.84	<.001
	Feeling something should change[a]	1.82	1.03 ; 2.61	<.001
	Binaural Hearing Impairment	0.01	0.01 ; 0.02	<.001
	Auditory work demands	0.20	0.14 ; 0.26	<.001
	Personal adjustments	-0.05	-0.06 ; -0.03	<.001

[a] Reference category = not feeling that something should change in the work situation.

Discussion

The aim of this study was to identify factors influencing NFR and LE in hearing-impaired employees. Four factors were shown to directly influence NFR and four factors were shown to directly influence LE.

In line with the literature arguing the theoretical assumption that increased LE may cause a sense of mental fatigue (McGarrigle et al., 2014), LE was found to be the factor with the highest association with NFR ($r = 0.527$) in the correlation analysis. In contrast, no significant associations were observed between the hearing test outcomes and NFR, including BHI, maximum discrimination score, and the critical SNR. While tinnitus has earlier been shown to be associated with NFR (Juul Jensen et al., 2018), we did not find a significant association in this study. This may be explained by the dichotomous question that we used that did not allow for differentiating in degree of tinnitus. Also, because we used routinely obtained healthcare data, we may have missed hearing-related factors, such as hyperacusis. For concepts related to NFR, mixed results are presented for hearing loss (Hornsby & Kipp, 2016; Svinndal et al., 2018). Pure-tone audiometry was not significantly related to fatigue and vigor (Hornsby & Kipp, 2016), but patients with more severe hearing loss reported lower workability and higher degrees of fatigue (Svinndal et al., 2018).

The lack of a significant association between SNR and NFR in the correlation analysis contrasts the results of an earlier study that found poorer SNR to be associated with higher NFR (Nachtegaal et al., 2009) In this earlier study, the SNR was derived from an adaptive digits-in-noise test performed over the internet and the subjects completed the test without hearing aids. In our study, routinely healthcare data were used, having the advantage that all hearing tests were performed in standardized audio cabins, but with the disadvantage that SNR data were missing in 158 patients (54%). Performing the speech reception test in noise is not obligatory in standard care. The choice to perform the speech reception test is determined by a patient's profession and associated auditory demands. Therefore, the missing SNR data are not missing at random, and the presence of confounding cannot be ruled out. Another explanation might be that we derived SNR's with and without hearing aids, to resemble patients' daily life work situation. Although we expected the SNR scores to be more strongly associated with NFR, this choice may have masked an existing association. Since BHI correlates with LE, but not with NFR, we presume that the degree of hearing loss is not the underlying factor explaining the moderate correlation between LE and NFR. In the directed acyclic graph, two factors show moderate correlations with both LE and NFR, specifically 'feeling that something should change at work' and PA. Apparently, the way employees perceive their hearing difficulties and how they cope with their hearing loss influence their LE and the fatigue experienced after a day of work. Likewise, subjective measures of perceived hearing difficulties were found to be strongly associated with fatigue and vigor, whereas there was no significant association with degree of hearing loss (Hornsby & Kipp, 2016). It would be interesting to compare our findings of (self-reported) LE with other measures of listening effort, such as measuring reaction time or pupil responses during speech reception tasks in noise (McGarrigle et al., 2014).

In line with De Vries et al. (2015) and Machin and Hoare (2008), we found a significant correlation between coping behavior and NFR. Specifically, we have explored two variables for coping behavior distinguishing the communication strategies that were used and the PA that were made. Although these scores showed a moderate correlation between themselves (r = 0.399), the PA score was directly related to LE and NFR, but the communication strategy score was not. Other studies report an association between communication strategies used and NFR (De Vries et al., 2015; Machin & Hoare, 2008). Having a passive reaction coping style explained 26 percent of the variance in NFR in employees with major depression in remission (de Vries et al., 2015). In a population of bus drivers, maladaptive driver coping behaviors were shown to be associated with NFR (Machin & Hoare, 2008). To our knowledge, previous studies have not focused on the association between NFR and PA, including self-acceptance, acceptance of loss, and stress and withdrawal. A qualitative study reported that self-acceptance facilitates work ability (Detaille et al., 2003). Distinguishing communication strategies and PA would be of interest in future studies with hearing-impaired employees to gain further understanding of the influence of coping behavior on NFR.

In addition to explore the influence of coping behavior, several other questions were included to assess the influence of PA. We observed that the factor 'feeling that something should change at work' was moderately associated with NFR, as well as with LE. The question 'Do you feel something should change in your work situation' may grasp a feeling of frustration at the workplace, that was earlier associated with NFR in seafarers (Bridger et al., 2010). Feeling frustration at the workplace might be associated with higher NFR. This finding must, however, be interpreted with caution, because we used a single question, rather than a validated questionnaire. The question may also reflect other constructs, such as the awareness or acceptance of functional hearing difficulties at the workplace. Although a firm conclusion can thus not yet been drawn, this finding underlines the importance to measure employees' frustration level in future research concerning NFR using a validated questionnaire.

In line with the previous studies (Gommans et al., 2015; Van der Starre et al., 2013), general health condition was found to be significantly associated with NFR, independently from the other factors. Age, gender, and educational level were considered to be potential confounders, but the correlation analysis showed that these factors were neither significantly associated with NFR, nor with hearing-related or personal factors. A similar independent position was found for the factor auditory work demands. This factor was moderately associated with LE. In contrast to the literature describing that auditory demands are significantly related to hearing handicap and sick leave (Kramer et al., 1998; Kramer et al., 2006), we did not find a significant association between auditory work demands and NFR. This may suggest that although high auditory demands increase the LE, the degree of feeling fatigued after work depends on other factors. The use of PA or being in good health may be protective for developing occupational problems. Future research is required to further assess these mechanisms.

Other work characteristics did neither influence NFR nor LE. First, we expected a positive association between the number of working hours and NFR (Jansen et al., 2002; Verdonk et al., 2010), but this was not the case. The lack of association could be explained if patients with high NFR had chosen to work fewer hours to prevent health problems. Since this study uses health administrative data, we cannot confirm this hypothesis. The directed acyclic graph showed that men had a higher number of working hours than women, which is a typical finding for the Dutch working population (Gjerdingen et al., 2001). Employees that reported a higher number of working hours, more often reported fulfilling managerial tasks and those fulfilling managerial tasks reported being more able to participate in work decisions. Second, in contrast to what was observed earlier (Van Veldhoven & Broersen, 2003), work participation was not associated with NFR. In other words, the feeling of job control did not directly influence NFR. Literature presents mixed results on the association between job control and NFR (Kraaijeveld et al., 2014; Sonnentag

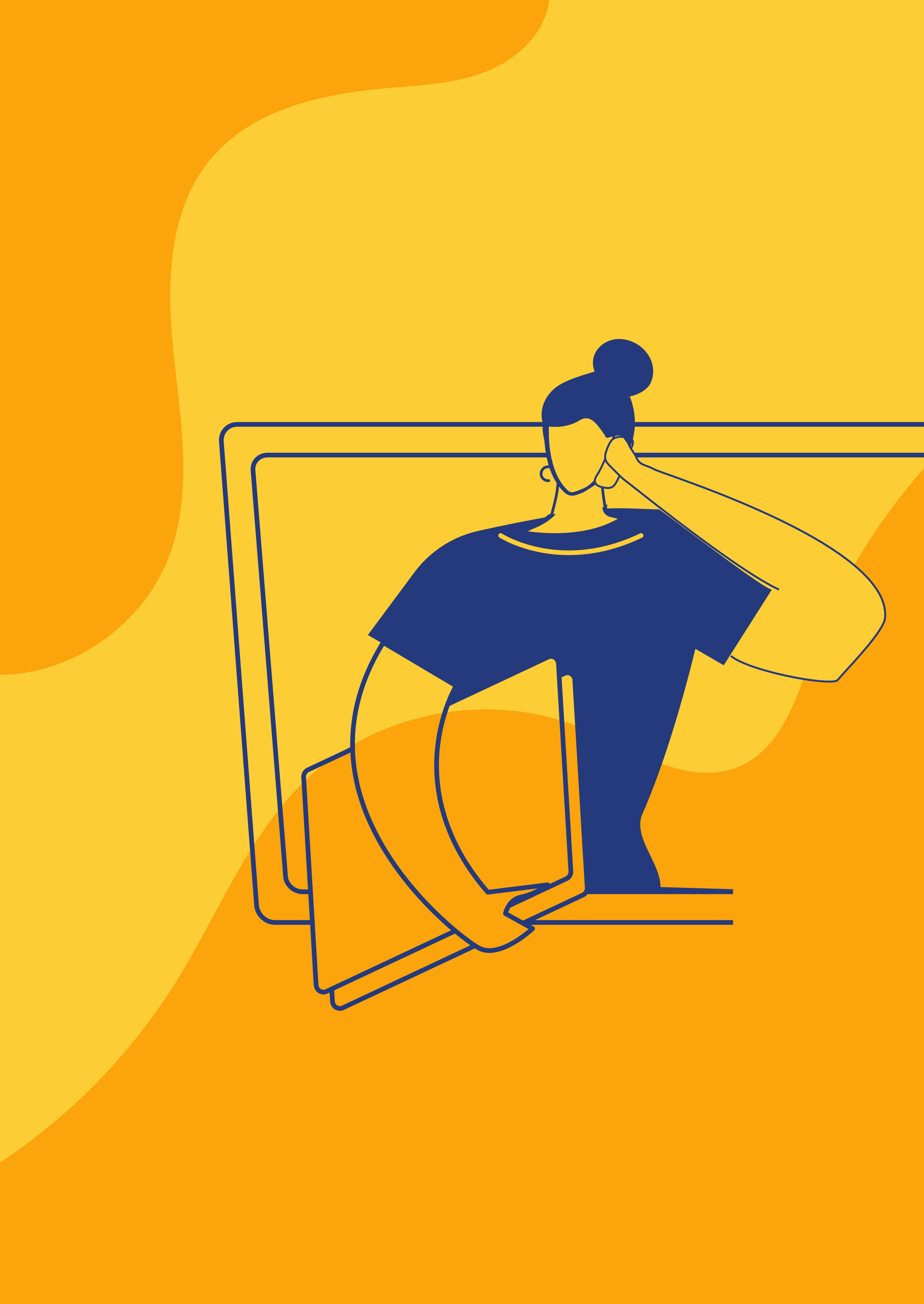
& Zijlstra, 2006; Van der Hulst et al., 2006). Third, receiving collegial support did neither influence 'the feeling that something should change at work', nor NFR as was earlier reported (Kraaijeveld et al., 2014). This might be explained by the small variance in collegial support reported by our population. Only a few employees reported having problems in their relationship with colleagues.

We have derived work-related factors from the QEEW and ACHW, because these questionnaires are routinely performed in the ENT-Audiology clinic. Therefore, we may have missed other work-related factors that influence NFR in hearing-impaired employees, such as job control, job demand, and social support. The included scale score of collegial support does not reflect all aspects of the construct social support, since this construct also refers to helpful social interactions from supervisors (Nachtegaal et al., 2009). For future research, we recommend to include the Job Content Questionnaire when measuring psychosocial work characteristics (Karasek et al., 1998).

Some study limitations should be noted. First, the retrospective character of the study implicates a risk for measurement bias. For example, the hearing tests were performed by multiple clinicians following clinical protocols, rather than a research protocol, which may have caused differences in measurement settings. Despite this limitation, the four identified factors accounted for 46.1 percent of the variance in NFR and 43.1 percent of LE. Second, the cross-sectional design is a limitation of this study, since it does not allow drawing conclusions about causality. Constructing a directed acyclic graph allowed for visualization of the relationship of a broad spectrum of factors influencing NFR. Since the evidence on factors influencing NFR in hearing-impaired employees was limited, this explorative method is considered to be appropriate. A prospective study is needed to verify and validate the findings of this study. To gain further understanding in the difficulties of hearing-impaired employees and the efficacy of intervention strategies that aim to reduce these difficulties, future clinical trials are recommended to assess the efficacy of audiological, speech therapeutic, and social interventions on both LE and NFR.

Concluding remarks

This study provides a framework of factors associated with NFR in hearing-impaired employees, contributing to the understanding of occupational problems in this population. The results suggest that the way employees perceive their hearing loss and how they cope with it directly influence NFR, rather than their measured degree of hearing loss. Further, when assessing or evaluating NFR, employees' general health condition should be considered. These findings are relevant for clinicians and occupational physicians that perform diagnostics or intervention strategies for hearing-impaired employees. Also, the results may contribute to gain understanding in the working mechanisms of interventions that aim to prevent or cure occupational diseases in employees with hearing loss.



Chapter 2

The relationship between hearing status, listening effort, and the need for recovery in employees of a manufacturing company

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Abstract

Objective

Hearing screening can be used to detect occupational hearing loss, but its value for identifying employees with work functioning difficulties is unclear. The objective of this study was to assess the association between the hearing status, listening effort, and need for recovery in employees of a manufacturing company, and to examine whether these associations depend on the perceived noise level at the workplace.

Methods

Employees of a provider of paints and coatings were included. Their hearing status was assessed with an occupational hearing-in-noise screening test. An online survey was used to assess their listening effort, need for recovery and the perceived noise level at the workplace. Responses from 143 employees were analyzed (mean age = 53 years) using hierarchical multiple regression analysis with the outcomes listening effort and need for recovery.

Results

Regression analysis – with adjustments for gender, age, educational level, health status, pace/amount of work, job variety, and work pleasure – revealed that hearing status was significantly associated with listening effort, but the interaction between hearing status and the subjective noise level was not. Hearing status nor the interaction between hearing status and the subjective noise level were significantly associated with need for recovery.

Conclusion

In line with previous research, the results confirm that poorer hearing is associated with higher listening effort, but not with higher need for recovery. These associations were unrelated to the perceived noise level at the workplace. Therefore, the value of occupational hearing screening appears to be early identification of hearing loss in employees, but not identification work functioning difficulties.

Introduction

Hearing loss is a common condition in the working population, with higher prevalence with higher age and in populations that are exposed to occupational noise (Hasson et al., 2010; Masterson et al., 2016; May, 2000; Nelson et al., 2005). In the last decades, there has been an increasing interest in the impact of hearing loss on work functioning (Danermark & Gellerstedt, 2004; Hasson et al., 2011; Kramer et al., 2006; Punch, 2016; Van der Hoek-Snieders et al., 2020). Even with mild hearing loss, the performance of auditory job tasks may take significantly more Listening Effort (LE), especially in noisy work environments (Kramer et al., 2006; Nachtegaal et al., 2009). Sustained, effortful listening can be fatiguing and is associated with higher Need For Recovery (NFR) after work (Van der Hoek-Snieders et al., 2020).

In line with earlier studies that indicate that high NFR is a predictor of negative work implications (De Croon et al., 2003; Sluiter et al., 2003), hearing loss has been found to hinder work participation. Some job tasks cannot be performed safely and effectively without sufficient hearing, which is for example the case in pilots, fire fighters, and locomotive engineers (Tufts et al., 2009). In these, but also in other occupations, work participation can also be under pressure when hearing loss is present. Hearing loss has been shown to be associated with reduced work productivity, higher levels of sickness leave due to mental distress, unemployment, and earlier retirement (Danermark & Gellerstedt, 2004; Hasson et al., 2011; Kramer et al., 2006; Punch, 2016; Svinndal et al., 2018).

In some workplaces, occupational hearing screening is applied to detect hearing loss in an early stage (Leensen et al., 2011). This serves several purposes. Occupational hearing screening can be used to ensure that employees can perform essential hearing-critical job tasks safely and effectively (Tufts et al., 2009). Also, noise-induced hearing loss is preventable, and occupational hearing screening can contribute to take preventive measures (Leensen et al., 2011). In the Netherlands, occupational hearing screening is routinely offered to employees that work in workplaces with noise levels above 85 dBA. Lastly, occupational hearing screening can stimulate employees to seek audiological help (Smits et al., 2004; Smits et al., 2006), before they experience listening difficulties or other difficulties at work.

Several hearing tests have been proposed for screening purposes. Otoacoustic emissions (OAEs) objectively measure the outer hair cell function, pure-tone audiometry evaluates the detection of sounds in a quiet environment, and speech-in-noise tests measure the ability to understand speech in a noisy environment (Rashid, 2018). Since difficulties with understanding speech in noise are the major complaint of people with hearing loss, speech-in-noise tests are considered most suitable for assessing functional hearing (Rashid, 2018; Smits et al., 2013). The Occupational Ear Check (OEC) is a Dutch speech-in-noise test that has been developed for occupational screening purposes (Ellis et al., 2006). For both ears separately, the signal-to-noise ratio (SNR) is assessed at which 50 percent of the speech stimuli can be identified correctly.

Many researchers have investigated the reliability and validity of speech-in-noise screening tests for identifying hearing loss, which is also the case for the OEC (Leensen, 2013; Rashid, 2018). However, it is yet unclear if the poorer screening outcomes are also associated with higher LE and higher NFR. Therefore, the value of occupational hearing screening for identifying employees with subjective listening difficulties and/or difficulties with work participation is still unclear.

In an earlier study, the outcome of a speech-in-noise test was significantly associated with LE, but not with the NFR (Van der Hoek-Snieders et al., 2020). This study included a clinical population and used a speech-in-noise test that is not designed for screening, but for clinical purposes. Also, the association between the outcome of the hearing screening, LE, and NFR might be different for employees that experience different noise levels at their workplace, but an interaction effect with occupational noise was not investigated thus far. Therefore, the aim of this study was to assess the association between the hearing status measured with an occupational hearing-in-noise screening test, LE, and NFR in employees, as well to examine whether these associations depend on the perceived noise level at the workplace.

Methods

Study design

This cross-sectional and observational study was conducted at a manufactural company that produces coatings. We analyzed the outcome of an online survey and the outcome of an internet-based hearing screening. This screening is routinely administered at the company as part of a voluntary administered health check. The ethics Committee of the Academic Medical Center declared that no formal approval of the detailed protocol was required according to the Dutch Medical Research Involving Medical Subjects Act (No. W18_369 # 18.421).

Population and procedures

With consent of the company's management, information about this study was provided in the period from December 2020 to February 2022 at the companies' intranet and in the coffee rooms of the factory workers. Also, employees who visited the occupational physician of the company for a routinely health check received information about the study. Participation was voluntary; employees who were interested in the study received an informed consent form and an online survey that could be accessed after providing consent. This survey was hosted by Castor, a highly secured, cloud-based electronic data capture platform (Castor, 2019). A reminder was sent by email to employees who did not complete the survey.

Employees could participate in the study regardless of their position in the company. Eligible employees were 40 to 68 years, spoke Dutch fluently, and completed the informed consent form. The informed consent included permission to receive the survey, to request for the OEC outcome at VeiligheidNL, and to use the outcomes for this study.

Outcome measures

Need for recovery

NFR was the primary outcome measure of the study, which was assessed with the NFR-scale score of the Questionnaire on the Experience and Evaluation of Work version 2.0 (QEEW2.0) (Van Veldhoven et al., 2015). This scale consists of six statements concerning the short-time effects of a day of work, such as 'I find it hard to relax at the end of a working day' and 'When I get home, people should leave me alone for some time'. All statements have four response options, respectively 'always', 'often', 'sometimes', and 'never'. The sum score of the scale can be converted to a scale score ranging from 0 to 100. A higher score indicates higher NFR.

Listening effort

LE was the secondary outcome of the study, which was assessed with the Amsterdam Checklist for Hearing and Work (ACHW). Employees were asked how much effort and concentration it takes to fulfill six hearing activities at their workplace, specifically detecting sounds, distinguishing sounds, communicating in quiet, communicating in noise, localizing sounds and being exposed to loud sounds. According to Van der Hoek-Snieders et al. (2020), we calculated a sum-score of the items. This score can range between 0 and 18.

Determinants

Hearing status

The ability to understand speech in noisy situations was assessed with the OEC; an internet-based speech-in-noise hearing screening that is hosted by VeiligheidNL (Sheikh Rashid & Dreschler, 2018). The stimuli consist of a closed set of eight equally intelligible CVC words that are presented in a stationary low-pass filtered masking noise. During this tests, the stimuli and the noise are presented via headphones. After presentation of the word, the corresponding button on a computer or telephone screen should be identified. The stimulus level decreases with 2 dB after every correct response and increases with 2 dB after every incorrect response. The first stimulus is presented at an SNR of 0 dB SNR and is followed by an up-down procedure with a 2 dB step size. After the first incorrect response, twenty stimuli are presented. The outcome of the OEC can be expressed as the speech reception threshold (SRT), which is calculated by averaging the SNR of the last ten stimuli. The SRT is determined for the right and the left ear separately. For clinical purposes, the screening outcome is pass if the SRT of at least one ear is -14.9 or lower. High sensitivity and moderate specificity have been established for the OEC, taking pure-tone audiometry as the reference standard (Sheikh Rashid & Dreschler, 2018).

Perceived workplace noise

The workplace noise intensity perceived by the employees was assessed by a visual analogue scale ranging from 0 (no noise at all) to 100 (very noisy).

Confounders

Since NFR is a complex construct that is influenced by personal and work-related factors (Gommans et al., 2015; Van der Hoek-Snieders et al., 2020), we controlled for several personal and work-related factors in the analysis. The personal factors include gender, age, educational level and perceived health status. Age was measured continuously. Educational level was categorized into three groups, respectively low (primary education, lower general secondary education, and preparatory secondary vocational education), medium (intermediate vocational training and general secondary education) and high (higher vocational education and university education). Perceived health status had four response categories, respectively very good, good, fair, and bad.

The work-related factors include the pace and amount of work, job variety, and work pleasure. These factors were measured with the three scales of the QEEW 2.0 consisting of statements measured on a five-point Likert scale. The sum score of the scales can be converted to a scale score ranging from 0 to 100 with higher scores representing more unfavorable scores. A higher score indicates higher pace and amount of work, less job variety, and less work pleasure. The scale pace and amount of work consists of six statements, for example 'Do you have to hurry'. The scale job variety consists of four statements, including 'Do you have enough variety in your work'? The scale work pleasure consists of five statements, including 'I enjoy my work'.

Statistical analysis

Descriptive statistics were generated to report the characteristics of the study population. Distributions of all variables were examined and checked on normality. We computed Pearson correlations between all dependent variables with the outcome measures and to gain insight into possible multicollinearity. Correlations between the dependent variables were allowed if they were lower than 0.60.

Hierarchical multiple regression analyses were conducted to assess the relationship between understanding speech in noise, NFR, and LE. For both outcomes, predictor variables were included in three blocks (forced entry). For each block, we calculated the change in amount of variance in the outcome variable that is explained by the dependent variables and the contribution of the individual predictors.

The blocks of independent variables were the same for the primary and secondary outcome measure. The first block included the possible confounders. A main effect of hearing status was added in the second block. In the third block, an interaction term was added, respectively the interaction between hearing status and the perceived noise level. A significance level of 0.05 was used.

Results

In total, 180 employees were interested to participate in the study of which eight did not respond on the study information and 29 could not be included because they were aged below 40. This resulted in a study population of 143 employees. Table 1 shows their demographics.

The majority (75%) of the study population was male, mean age was 53, and their educational level varied from primary school to university. Most employees (89%) reported their health condition to be very good or good, and the others reported their health condition to be fair (10%) or bad (1%). Most employees (65%) used hearing protection at work. Only a few employees (4) were hearing aid users. The outcome of the hearing screening was pass for 89% of the employees and fail for the other 11%.

Table 1. Demographic characteristics of the study population (*N* = 143)

	Category	***N***	**%**
Gender	Male	107	74.8
	Female	36	25.2
Age	40-50	50	35
	50-60	73	51
	>60	20	14
Educational level	Primary school	4	2.8
	Lower vocational	10	7.0
	General intermediate	9	6.3
	Vocational Education and Training	48	33.6
	General secondary	8	5.6
	Higher vocational	45	31.5
	University	19	13.3
Perceived health status	Very good	25	17.5
	Good	103	72.0
	Fair	14	9.8
	Bad	1	0.7
Hearing protection	Yes	93	65.0
	No	50	35.0
Hearing aids	Yes	4	2.8
	No	138	97.2

A normal distribution was confirmed for all variables. Table 2 shows the relationships between the variables. The correlations between all independent variables were below 0.60 and thus there was no indication of multicollinearity. Hearing status was significantly associated with LE ($r = .39, p < .01$), but not with NFR ($r = .12, p = .74$).

Table 2. Means, standard deviations and Pearson correlations between personal factors, work-related factors, hearing status, listening effort, and need for recovery ($N = 143$)

	1. Gender	2. Age	3. Educational level	4. Health status	5. Pace/amount of work	6. Job variety	7. Work pleasure	8. Hearing status	9. Noise level	10. Need for recovery	11. Listening effort
M	-	53.1	-	-	36.4	62.3	24.6	-17.0	36.0	22.7	2.5
SD	-	6.9	-	-	15.1	17.0	17.3	2.1	24.3	15.3	2.2
1.		-.12	.22**	.06	.22**	.04	-.01	.14	-.30**	.14	-.10
2.			-.14	-.03	-.14	-.08	-.07	.25	.08	-.16	-.12
3.				-.20*	.28**	.30**	-.06	-.28*	-.43**	.27**	.03
4.					-.05	-.25**	.16	.20	.15	.10	-.02
5.						.18*	.21*	.01	-.27**	.43**	.04
6.							-.31**	-.24	-.05	.12	.05
7.								.25	-.05	.34**	.03
8.									-.06	.04	.39**
9.										-.18*	.12
10.											.33**
11.											

* p<.05, **p<.01.

Table 3. Results of the hierarchical multiple regression analysis of the factors associated with need for recovery and listening effort

	Block	Predictors	*p*
Need for recovery	1	Gender	ns
		Age	ns
		Educational level	.02
		Health status	.04
		Pace/amount of work	<.01
		Job variety	ns
		Work pleasure	<.01
	2	Hearing status	ns
	3	Hearing status	ns
		Hearing status x perceived workplace noise	ns
Listening effort	1	Gender	ns
		Age	ns
		Educational level	ns
		Health status	ns
		Pace/amount of work	ns
		Job variety	ns
		Work pleasure	ns
	2	Hearing status	.02
	3	Hearing status	.03
		Hearing status x perceived workplace noise	ns

Gender, age, educational level, health status, pace/amount of work, job variety, and work pleasure were entered as predictors in Block 1 and as control variables in Block 2.

The results of the hierarchical multiple regression analysis are presented in Table 3. It shows that hearing status nor the interaction between hearing status and the subjective noise level were significantly associated with NFR. Hearing status was significantly associated with LE, but the interaction between hearing status and the subjective noise level was not.

Regarding the outcome NFR, the change in explained variance was significant for the first block (R square change = .314, p < .01), but not for the second block (R square change = .000, p = .96) nor the third block (R square change = .001, p = .69). The percentage explained variance for all three blocks was 27 percent.

For the outcome LE, the change in explained variance was significant when the second block was included (R square change = .07, p >.01), but not for the first block (R square change = .031, p = .74) nor the third block (R square change = .015 p = .14). The model including the possible confounders explained only 3 percent of the variance. The second model, after inclusion of hearing status, explained 10 percent of the variance. The third model, after inclusion of hearing status and the interaction between hearing status and the subjective noise level, explained 12 percent of the variance.

Discussion

Many researchers have assessed the reliability and validity of speech-in-noise screening tests for identifying hearing loss, but it was unclear if poorer screening outcomes are also associated with higher LE and higher NFR. We found that hearing status was significantly associated with LE, but not with NFR in a population of employees of a manufacturing company. The associations did not depend on the perceived noise level at the workplace.

The finding that poorer hearing is associated with higher LE during the performance of auditory job tasks is in line with earlier studies in clinical populations (Kramer et al., 2006; Van der Hoek-Snieders et al., 2020). It suggests that the performance of auditory job tasks can be more demanding for employees with poorer hearing. It should however be noted that only weak to moderate associations were found in these studies: $r = .39$ in this study and $r = .20$, and $r = .69$ in the earlier studies of Van der Hoek-Snieders et al. (2020) and Kramer et al. (2006) respectively. This implies that the effort it takes to perform auditory job tasks is only partly determined by hearing status. For example, cognitive load and speaker characteristics play a role according to the classification of Mattys et al. (2012), such as pronunciation, disfluencies, and speech disorders. This might suggest that LE at work also depends on the complexity of the job task and on speaker characteristics of colleagues.

A non-significant association was found between hearing status and NFR. Earlier, mixed results were presented regarding the association between the ability to understand speech in noise and NFR (Nachtegaal et al., 2009; Van der Hoek-Snieders et al., 2020; Van Leeuwen et al., 2021). A significant association was found in the cross-sectional study of Nachtegaal et al. (2009) and in the longitudinal study of Van Leeuwen et al. (2021). These studies included adults with normal hearing and adults with various degree of hearing loss. No significant association was found in the cross-sectional analyses of Van der Hoek-Snieders et al. (2020, 2022). They included employees that visited an audiological center, because of hearing complaints in their work situation. The degree of hearing loss was moderate in the majority of these employees. The mixed study results might be explained by the population differences between the studies, since an association is more likely to be demonstrated when there is larger variation in the degree of hearing loss.

Although it is assumed that the impact of poorer hearing on LE may be greater in noisy work environments (Kramer et al., 2006; Nachtegaal et al., 2009), we did not find a significant association between the perceived workplace noise and LE. Furthermore, no significant interaction effect was found between hearing status and perceived workplace noise in predicting hearing status. An explanation might be that – considering the OEC outcome – the vast majority of the study population is expected to be normally-hearing. Possibly, small differences between normally-hearing employees are not associated with LE, even not in noisy work environments. Another explanation might be that hearing protection was used by 65 percent of the employees under study, since hearing protection is expected to reduce the hindrance of loud noises. The interaction between hearing status and perceived workplace noise for predicting LE and NFR should be assessed in a population with higher degree of hearing loss.

Some study limitations should be noted. There is a risk for selection bias, since employees voluntarily participated in this study. For example, feeling insecure about the hearing status might have been a reason to not participate in the study. Also, because there is currently no validated questionnaire available that measures LE during hearing-related job activities, we used a non-validated questionnaire. Lastly, we controlled for a broad spectrum of confounders. Nevertheless, we are not sure that we controlled for all relevant confounders since NFR is a complex construct. For example, the cognitive load of employees job might have been relevant.

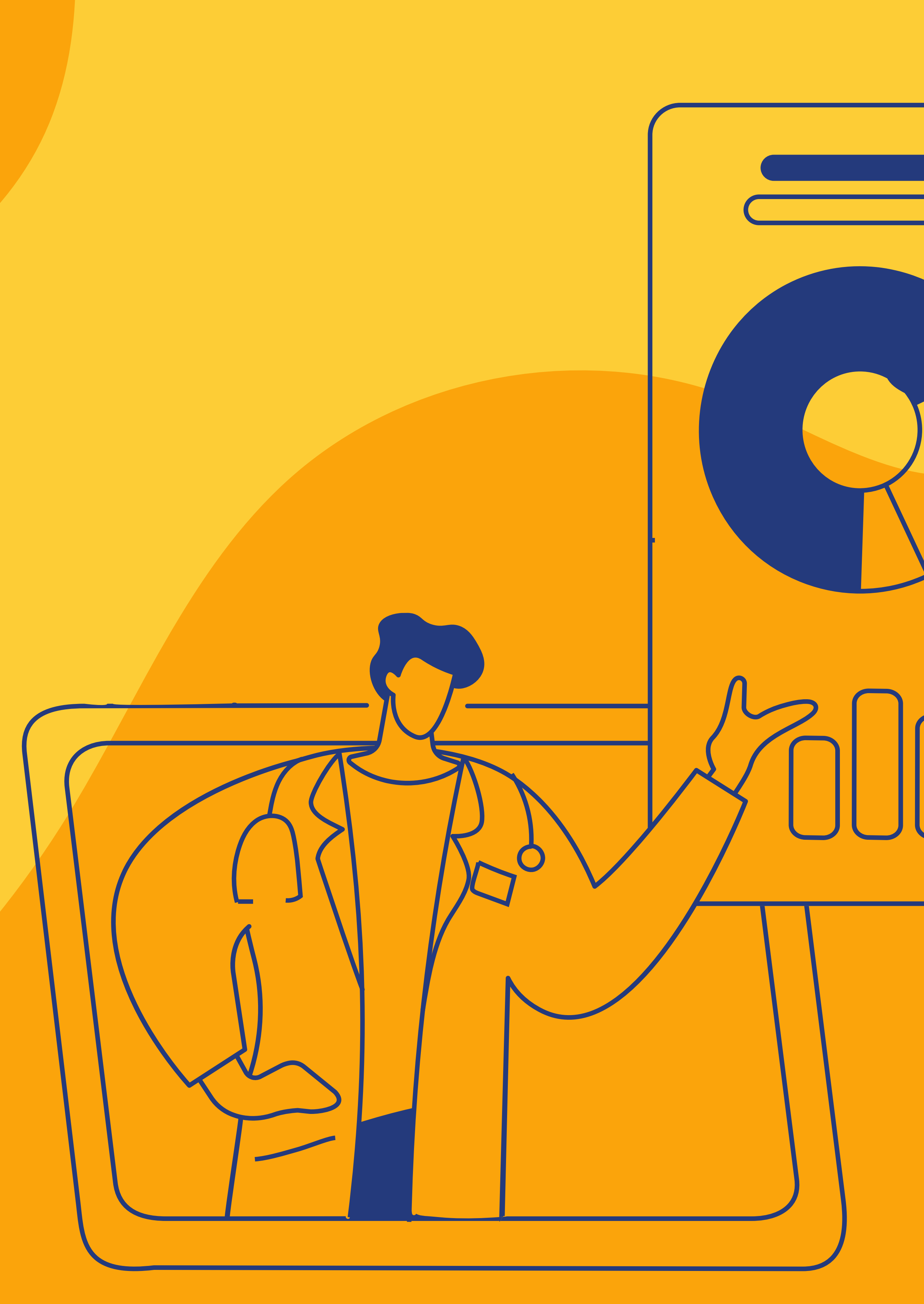
Considering the moderate association between hearing status and LE, the OEC is expected to inadequately predict subjective listening difficulties at the workplace at individual level. The predictive value of the OEC for high NFR is expected to be even poorer. Although the OEC is an appropriate instrument to assess employees' ability to understand speech in noisy environments (Leensen, 2013; Rashid, 2018), the added value of occupational hearing screening for the identification of subjective listening difficulties and/or difficulties with work participation is modest. Occupational hearing screening might be valuable to rule out hearing loss as an underlying cause of listening difficulties or difficulties with work participation, for example in employees that present with complaints of fatigue after work. This should be investigated by future research.

Conclusion

Our results confirm that poorer hearing is associated with higher LE, but not with higher NFR. These associations were unrelated to the perceived noise level at the workplace. Therefore, the value of occupational hearing screening appears to be primarily in early identification of hearing loss in employees, but not in the identification of subjective listening difficulties and/or difficulties with work participation. Future research should investigate the value of occupational hearing screening for identifying hearing loss as a hidden cause of work participation difficulties.

Part II

Evaluation of professional functioning



Chapter 3

Factors associated with change in the need for recovery and subjective listening effort in employees with hearing loss receiving aural rehabilitation

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Abstract

Objective

Compared to normally-hearing employees, those with hearing loss suffer from higher need for recovery after work. The aims of this study are to assess the need for recovery of employees with hearing loss before and after aural rehabilitation and to examine to what extent change in the need for recovery can be explained by changes in subjective listening effort, personal adjustments, communication strategies, auditory work demands, and self-reported hearing ability.

Methods

We included patients who received aural rehabilitation in two audiological centers in the Netherlands because of hearing complaints in their work situation. Outcomes were measured by questionnaires at baseline and three months follow-up. The need for recovery before and after the rehabilitation was compared with a t-test. Hierarchical multiple analyses were performed.

Results

In total, 60 patients (aged 22-63, working hours ≥8 per week) participated in the study, of which 50 completed the follow-up questionnaires. The need for recovery was significantly lower after the aural rehabilitation ($M = 45.03$) compared to before the aural rehabilitation ($M = 51.89$), $t = -3.43$, $p < .01$). Change in NFR could best be explained by the change in personal adjustments ($R^2 = .45$, $B = -1.23$, $p < .01$).

Conclusion

The NFR of employees with hearing loss can be improved by aural rehabilitation, but this study shows that current practices reduce the need for recovery only in part of the employees. Therefore, improving current practices should be considered and evaluated, for example by applying a different combination of rehabilitation components. Especially, interventions that affect personal adjustments may be promising to further reduce the need for recovery in employees with hearing loss.

Introduction

Hearing loss is a prevalent health problem and can severely affect the well-being and work functioning of employees (Danermark & Gellerstedt, 2004). It causes more effort and concentration to be required to perform auditory job tasks, such as communicating with colleagues or responding to auditory warning signals (Tufts et al., 2009). Sustained listening under difficult conditions – such as noisy workplaces or workplaces with reverberation – can be demanding and fatiguing (Holman et al., 2019; Hornsby et al., 2016). Compared to normally-hearing employees, those with hearing loss experience more intense fatigue, and/or require a longer period to recuperate from work-induced fatigue (Holman et al., 2021a; Nachtegaal et al., 2012; Nachtegaal et al., 2009). In other words; their Need For Recovery (NFR) after work is generally higher.

NFR is not only an indicator of work-induced fatigue, but also a predictor of stress, subjective health complaints, and sickness leave (De Croon et al., 2003; Sluiter et al., 2003). Assessing the NFR can therefore be used to screen for employees at risk for occupational diseases (Broersen et al., 2004). Employees with hearing loss are more likely to have reduced work productivity, to take more sickness leave, to become unemployed, and to take earlier retirement (Danermark & Gellerstedt, 2004; Helvik et al., 2013; Mohr et al., 2000; Nachtegaal et al., 2012; Shan et al., 2020). Monitoring the NFR of employees with hearing loss may therefore be valuable to identify employees at risk for occupational diseases. Monitoring can also be used to evaluate the effects of interventions that aim to reduce hearing complaints in work situations and to improve work participation in individuals with hearing loss.

Recently, there has been an increasing interest in the NFR of employees with hearing loss. In our previous study (Van der Hoek-Snieders et al., 2020), NFR and the underlying relationships with several hearing-related, work-related, and personal factors was assessed in 294 employees with hearing loss. A model was proposed of factors influencing the NFR in this population (Figure 1).

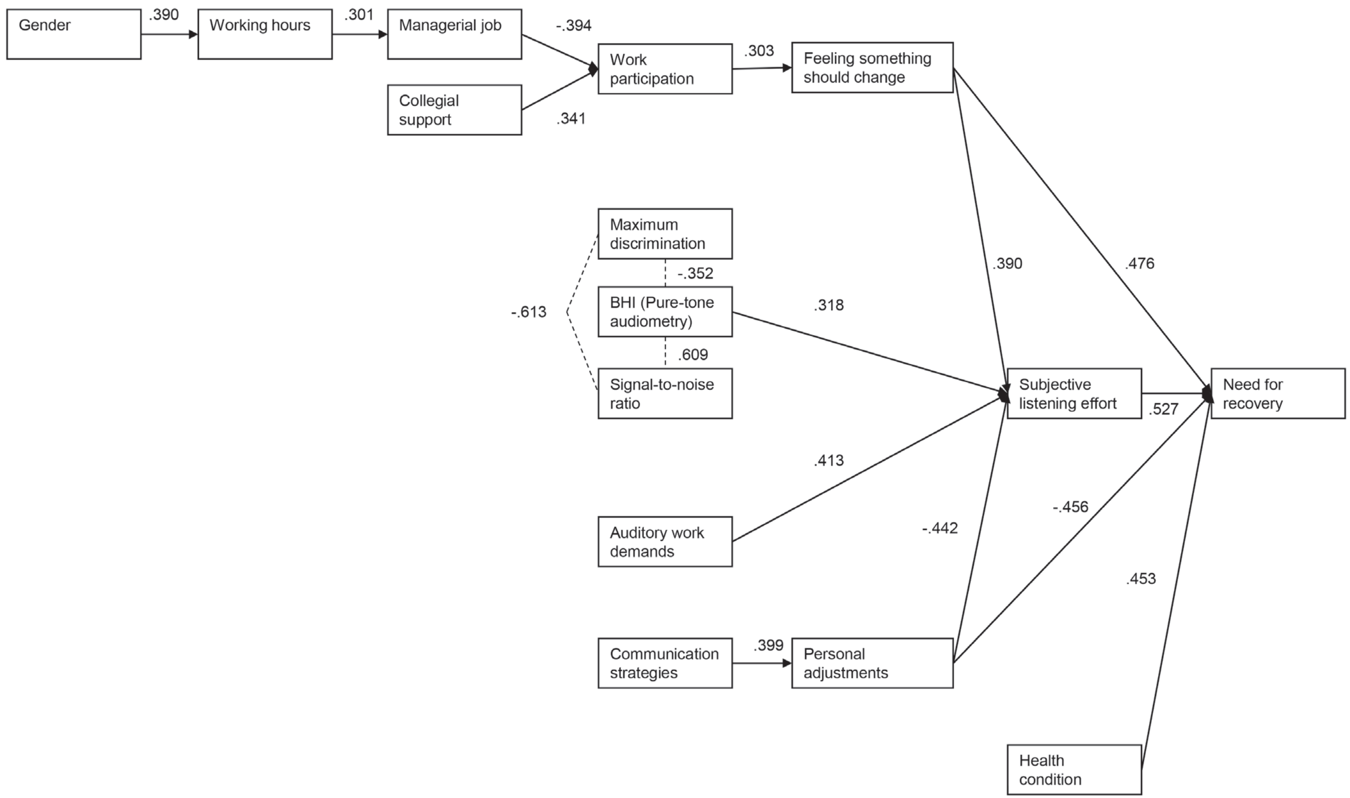


Figure 1. Model of factors influencing the need for recovery of employees with hearing loss as proposed by Van der Hoek-Snieders et al. (2020). BHI indicates Binaural Hearing Impairment.

NFR is influenced by subjective Listening Effort (LE) and some factors influence both NFR and LE according to this model. Specifically, NFR and LE are influenced by 'the feeling that something should change at work' and by making personal adjustments, which include self-acceptance, acceptance of loss, and stress and withdrawal. It was found that 'feeling that something should change at work' and a poorer ability to make personal adjustments were associated with higher NFR and higher LE.

Differences between the constructs NFR and LE were also reported in that study. According to the model, NFR is influenced by employees' general health condition, but LE is not. Reporting a moderate or poor health condition, rather than a good health condition, was found to correlate moderately with a higher NFR. Furthermore, it was found that LE is influenced by employees' hearing status measured with pure-tone audiometry, but NFR is not. Earlier studies report inconsistent results regarding the association between hearing status and NFR (Nachtegaal et al., 2009; Wang et al., 2018).

It should be noted that the hypothesized model of our previous study (Van der Hoek-Snieders et al., 2020) has been constructed based on the correlations found in their study sample, and the model has not yet been validated in an independent sample. Also, this previous study was based on cross-sectional data. Therefore, the data do not allow strong statements about the causality regarding the effect of the interventions on the NFR of employees with hearing loss.

Most interventions provided to employees with hearing loss can be captured within the domain of aural rehabilitation. The aim of aural rehabilitation is to reduce hearing complaints in social life and in work situations and to improve work participation and daily life functioning (Boothroyd, 2007, 2017). It can consist of four components, respectively sensory management (e.g., the provision of hearing aids), perceptual training, instruction, and counselling. Instruction is a more directive manner of psycho-education, whereas counselling is more person-centered.

Recently, Granberg and Gustafsson (2021) concluded in a scoping review that the literature regarding rehabilitation services for employees with hearing loss is scarce. It is for example not well described which disciplines should be involved or which specific services should be provided. In the Netherlands, individually tailored aural rehabilitation is usually applied by an audiologist and sometimes also by an occupational physician, social worker, psychologist, or speech therapist. Based on the patients' needs, the rehabilitation consists of interventions belonging to one or more of the four components mentioned above. Although it is increasingly acknowledged that it is important to address patient's work needs in aural rehabilitation (Granberg & Gustafsson, 2021; Zuriekat et al., 2021), due to the lack of literature, it is unclear to what extent these kinds of services are currently provided and what the effects are of current services. To the best of our knowledge, a prospective evaluation of the NFR after the provision of any kind of aural rehabilitation has only been conducted in two recent studies (Gussenhoven et al., 2017; Van Leeuwen et al., 2021).

Gussenhoven et al. (2017) performed a randomized controlled trial comparing a multidisciplinary program of aural rehabilitation including vocational and audiological components with audiological care as usual. They included employees experiencing hearing difficulties and restrictions at work due to their hearing loss. No significant decrease in the NFR was found in both groups at 3, 6, 9, or 12 months follow up, and the effect of the intervention on the NFR did not differ between the two groups. Van Leeuwen et al. (2021) performed a cohort study and evaluated the effect of using hearing aids and/or hearing assistive listening devices on the NFR. They included employees aged 18 to 67 with normal hearing or with hearing loss. A total of 147 employees with hearing loss were included who did not use hearing aids nor hearing assistive listening devices at baseline, but would be eligible for hearing aids based on their result on an online digit-triplet speech in noise test. After five years, 29 of them reported to use hearing aids and/or hearing assistive listening devices and 118 were not. Van Leeuwen et al. (2021) concluded that the uptake of hearing aids and/or hearing assistive devices did not have a significant effect on NFR.

It can thus be concluded that a positive effect of aural rehabilitation on the NFR has not yet been demonstrated. Also, there are no studies available investigating factors associated with change in the NFR of employees with hearing loss who receive aural rehabilitation. Such research would be useful for evaluating and optimizing the aural rehabilitation strategies that are currently used. Therefore, the study objectives are:

- To determine whether the model of Van der Hoek-Snieders et al. (2020) can be confirmed in a different population regarding the factors influencing the NFR and LE in employees with hearing loss;
- To assess the NFR of employees with hearing loss before and after aural rehabilitation

- To examine to what extent change in the NFR can be explained by changes in subjective listening effort, personal adjustments, communication strategies, auditory work demands, and self-reported hearing ability.

Methods

Study design

This prospective study was performed in employees with hearing loss who received aural rehabilitation at two audiological centers in the Netherlands, respectively at one location of the Amsterdam University Medical Center (UMC) and at three locations of Libra Revalidation and Audiology. Outcomes were measured by an extensive online questionnaire at baseline (T_0) and three months follow-up (T_1). Between T_0 and T_1, patients received different components of aural rehabilitation.

Participants

Eligible patients were referred to the audiological center of the Amsterdam UMC between 2019 and 2021 or the audiological center of Libra Revalidation and Audiology between 2020 and 2022. The inclusion criteria further required patients to be aged between 18 and 67, to visit the audiological center because of hearing complaints in the work situation, and to provide informed consent for participating in this study. Hearing complaints in the working situation could either be the reason of the referral to the audiological center or these complaints were concluded after the intake with the audiologist. Eligible patients received information about the study and were asked consent for using their responses on the baseline questionnaire (part of the routine health care process) for this study, for sending a second survey for research purposes after three months, and for accessing their patient file to extract their pure-tone audiometry results and the type of intervention that was applied. Patients were excluded if the reason for their referral was an auditory fitness for job assessment, because these patients visit the audiological center to ensure that they can perform their job safely and effectively rather than to reduce their LE and NFR. Patients were also excluded if the first visit at the audiological center was cancelled, if the baseline questionnaire was not filled in or was filled in after the start of the intervention, and if there was no indication for aural rehabilitation (Figure 2). The audiologist (routine clinical care) decided whether there was an indication for aural rehabilitation or not. Table 1 shows the demographic and clinical characteristics of the patients.

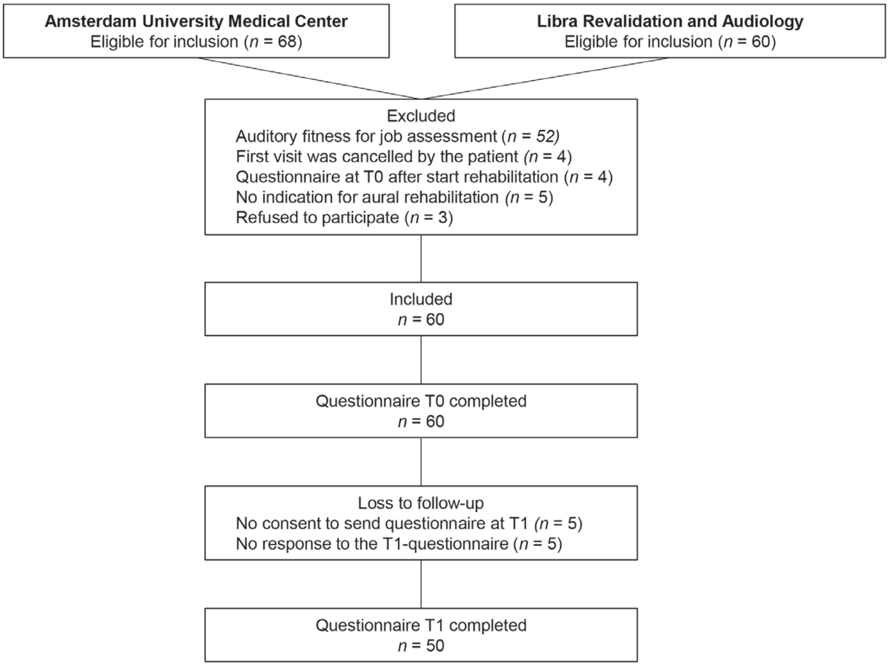


Figure 2. Flow chart showing the participants that were included in this study, exclusions, and the completion of the questionnaires at T0 and T1

Table 1. Baseline characteristics of the included participants (*N* = 60)

	Mean (sd)	Range	No. (%)
Age in years	48.0 (11.3)	22 - 63	
Gender, male			18 (30.0%)
General health condition, good			48 (80.0%)
Educational level			
Lower vocational			1 (1.7%)
General intermediate			4 (6.7%)
Intermediate vocational			18 (30.0%)
General secondary			2 (3.3%)
Higher vocational			25 (41.6%)
University			10 (16.7%)
Work sector			
Healthcare and public welfare			20 (33.3%)
Business and financial services			11 (18.3%)
Education			12 (20.0%)
Construction industry			7 (11.7%
Trade and catering			7 (11.7%)

	Mean (sd)	Range	No. (%)
Other			3 (5.0%)
Number of working hours	30.7 (8.1)	8 - 45	
Hearing aids, yes			37 (61.7%)
Binaural hearing impairment	42.8 (19.9)	5.6 – 88.6	
Auditory work demands [a]	29.7 (7.0)	16 – 45	
SSQ[b]			
Speech	5.5 (1.7)	1.0 – 9.1	
Spatial	4.5 (2.1)	0.0 – 10.0	
Quality	6.6 (1.9)	1.75 – 10.0	
Need for recovery[c]	50.1 (21.8)	0 – 100	
Subjective listening effort[d]	10.0 (3.4)	2 – 18	
Feeling something should change, yes			21 (35.0%)
Personal adjustments[e]	51.6 (12.9)	21 – 77	
Communication strategies[f]	68.5 (9.0)	45 - 86	
Self-acceptance mean item score	3.7 (1.0)	1.3 – 5.0	
Acceptance of loss mean item score	3.2 (0.9)	1.3 – 5.0	
Stress and withdrawal mean item score	3.0 (0.9)	1.1 – 4.9	

SSQ indicates Speech, Spatial, and Qualities of hearing scale.
[a] Higher score indicates higher auditory work demands.
[b] Higher score on the SSQ indicates greater self-reported hearing ability.
[c] Higher score indicates higher level of need for recovery.
[d] Higher score indicates higher level of subjective listening effort.
[e] Higher score indicates more adequate personal adjustments.
[f] Higher score indicates more adequate communication strategies.

Aural rehabilitation

All patients received individually tailored aural rehabilitation.

Sensory management interventions could include the provision and fitting of hearing aids and other assistive listening devices, such as table microphones. We distinguished the provision and fitting of hearing aids in patients who did not use hearing aids at T_0 (First HA), patients who used one hearing aid at T_0 and received a second hearing aid (bilateral fitting), patients who used hearing aids at T_0 and received new hearing aids (repeated fitting), and patients who used hearing aids at T_0 of which the settings were optimized (fine tuning HA). Sensory management interventions were provided by or under supervision of an audiologist.

Perceptual training could involve a speech reading training. This training could be provided individually or the patient could be referred for a group training. Perceptual training was provided by a speech therapist and a social worker.

Instruction and counselling were described as one category, because we expected that the subtle difference between instruction and counselling could not be recognized easily based on a patient file. The instruction/counselling could focus on coping – the development of effective listening strategies and coping behavior – or on work adjustments, such as adjusting working hours or environmental changes that improve room acoustics at the workplace. The instruction/counselling could be provided by an audiologist, psychologist, social worker, or an occupational physician.

We retrospectively derived the details of the provided aural rehabilitation components (sensory management, perceptual training, instruction/counselling) from patient files (Table 2). Regarding the component sensory management, we distinguished First HA, bilateral fitting, repeated fitting, fine tuning HA, and listening devices. Regarding the component instruction/counselling, we distinguished whether there was a focus on coping or on work adjustments.

Table 2. Aural rehabilitation services that were provided in the study population (N = 60)

	First HA (n = 14)	**Bilateral fitting (n = 2)**	**Repeated fitting (n = 15)**	**Fine tuning HA (n = 23)**	**No HA intervention (n = 6)**
No other	9	-	4	4	1
Listening devices	2	1	6	1	-
Coping counselling	3	1	2	3	2
WA counselling	-	-	-	4	-
Listening devices & coping counselling	-	-	-	3	1
Listening devices & WA counelling	-	-	2	3	-
Perceptual training & coping counselling	-	-	-	2	-
Coping counselling & WA counselling	-	-	1	3	2

HA indicates Hearing Aid; WA, Work Adjustments.

Questionnaires

At T_0 and T_1, patients receive questionnaires by email. The questionnaires at T_0 and T_1 are the same, except for demographics that were only included at T_0 (age, gender, general health condition, educational level, work sector, number of working hours). The questionnaires included questionnaires assessing the NFR, LE, 'feeling that something should change at work', personal adjustments, communication strategies, auditory work demands, and self-reported hearing ability.

The baseline questionnaires are routinely administered at the two audiological centers. The moment that patients receive these questionnaires slightly differ between the two centers. Patients who visited the Amsterdam UMC received the baseline questionnaire before the intake at the audiological center. Patients who visited Libra Revalidation and Audiology received the baseline questionnaire just after the intake with the audiologist. The follow-up questionnaires are not routinely administered at the audiological centers and was sent for research purposes.

All questionnaires were sent via the clinical management program Castor Electronic Data Capture (Castor, 2019). This program complies with the Good Clinical Practice guidelines.

Primary outcome measure

NFR was assessed using the NFR scale that is part of the Questionnaire on the Experience and Evaluation of Work 2.0 (QEEW 2.0) (Van Veldhoven et al., 2015). This scale consists of six statements, such as 'Because of my job, at the end of the working day I feel rather exhausted' and 'I find it hard to show interest in other people when I have just come home from work'. These statements have four response categories, respectively: always, often, sometimes, or never. The sum score can be converted to a scale score that ranges from 0 to 100, with higher scores indicating higher levels of NFR.

Secondary outcome measure

LE was inventoried with six questions on a 4-point response scale using the Amsterdam Checklist for Hearing and Work. The questions concern the effort it takes to perform six hearing-related job activities, respectively detecting sounds, distinguishing sounds, communication in quiet, communication in noise, localizing sounds, and being exposed to loud sounds. In accordance with Van der Hoek-Snieders et al. (2020), a sum score was calculated of these six questions. This score can vary between 0 and 18.

Determinants

Feeling that something should change

'Feeling that something should change at work' was assessed with a single, dichotomous question: do you feel that something should change in your work situation?

Personal adjustments and communication strategies

The shortened and validated version of the Communication Profile for the Hearing Impaired (CPHI) was used to assess personal adjustments and communication strategies (Lidwine B. Mokkink et al., 2010). This questionnaire aims to distinguish between adequate and inadequate coping behavior in people with hearing loss. The domain personal adjustments consists of three scales, respectively self-acceptance (4 questions), acceptance of loss (3 questions), and stress and withdrawal (9 questions). Questions include statements, such as 'I feel ashamed if I have to ask someone to repeat himself' (self-acceptance), 'I find it difficult to accept that I am hard of hearing (acceptance of loss), and 'I often withdraw because of my hearing loss' (stress and withdrawal). The domain communication strategies consists of three scales, respectively maladaptive behavior (7 questions), verbal strategies (7 questions), and non-verbal strategies (5 questions). Questions include statements, such as 'I avoid conversations with strangers, because of my hearing loss' (maladaptive behavior), 'I have asked my friends and colleagues to attract my attention before talking to me' (verbal strategies), and 'I always try to watch a persons' face' (non-verbal strategies). Responses are given on a 5-point scale with higher scores indicating more favorable coping strategies. Part of the statements has a frequency response scale (almost never, sometimes, regularly, usually, almost always) and the other statements have an agreement response scale (strongly disagree, disagree, uncertain, agree, strongly agree). We calculated the sum score of the personal adjustments and communication strategies scales according to Van der Hoek-Snieders et al. (2020), and the mean item score of the six sub scales.

Auditory work demands

Using the Amsterdam Checklist for Hearing and Work, the occurrence of six hearing-related job activities was inventoried on a 4-point response scale. A weighted sum score for auditory work demands was calculated according to Van der Hoek-

Snieders et al. (2020). Communication in quiet and distinguishing sounds received a weighting of 1, detecting sounds and localizing sounds received a weighting of 2, and being exposed to loud sounds and communication in noise received a weighting of 3. This score can vary between 0 and 48. The psychometric properties of this part of the Amsterdam Checklist for Hearing and Work have not been investigated yet.

General health condition

Patient's general health condition was inventoried with a single question: how is your general health condition? Response categories were good, moderate, and poor. In accordance with Van der Hoek-Snieders et al. (2020), the answers to this question were dichotomized for the statistical analysis (good versus moderate/poor).

Binaural Hearing Impairment

Pure-tone audiometry was performed as part of the routinely health care at the audiological centers. The degree of hearing loss was quantified by calculating the Binaural Hearing Impairment (BHI), defined as the mean pure-tone thresholds for air conduction at 1000 Hz, 2000 Hz, and 4000 Hz with a 5:1 weighting favoring the better ear (American Academy of Otolaryngology (Committee on Hearing 1979) .

Self-reported hearing ability

Self-reported hearing ability was assessed with the Speech, Spatial, and Qualities of hearing scale (SSQ) (Gatehouse & Noble, 2004). We used the Dutch version 3.2.1 (2007) that is also available in a shortened form: 17 questions, divided into three domains (Knoop et al., 2021) The first domain, speech comprehension (7 questions), assesses the ability to understand speech in different situations, such as situations in silence, with competing speakers, or in situations with continuous noise. In the second domain, spatial hearing (3 questions), the ability to locate sounds is measured as well as the ability to estimate the distance of sounds. The third domain, quality of hearing (7 questions), assesses the ease of listening, and the naturalness, clarity, and recognizability of different sounds. For each question, the self-rated ability is reflected by a score between 0 and 10, on a visual analogue scale, with higher scores reflecting greater ability (less disability). The average score was calculated for the three scales separately. Due to a programming error, the last question ('Can you easily ignore other sounds when trying to listen to something?') was not included in our questionnaire. Therefore, the average score of the quality of hearing scale and the average of all questions was calculated without considering the answer on this question.

Statistical analysis

Patients' baseline characteristics (Table 1) were described using descriptive statistics, as well as the components of aural rehabilitation that were provided (Table 3). We used histograms to check if the assumption of normality was fulfilled for the outcomes NFR, LE, personal adjustments, communication strategies, binaural hearing impairment, auditory work demands, and self-reported hearing ability.

In order to verify whether the patients of the Amsterdam UMC could be analyzed together with the patients of Libra Revalidation and Audiology, t-tests were performed to evaluate group differences. No differences were found in the demographic and clinical characteristics between the patients who visited the Amsterdam UMC and the patients who visited Libra Revalidation and Audiology. Therefore, the results of all patients were described and analyzed together.

To assess the first research question, correlation coefficients were calculated between NFR/LE and the factors of the model. We calculated the correlation coefficients in the same way as in our previous study (Van der Hoek-Snieders et al. 2020). The Pearson correlation coefficients were used to calculate the correlation between two continuous variables and Bi-serial correlation coefficients (Kraemer, 2014) were used to calculate the correlation between a continuous and a dichotomous variable. The interpretation of the correlation coefficients was weak (<0.3 or >-0.3), moderate (between 0.3 and 0.7 or between -0.3 and -0.7), or strong (>0.7 or <-0.7) (Ratner, 2009). According to Spence and Stanley (2016), we calculated 95% prediction intervals around the correlations found in the previous study. This calculation was based on a replication sample size of 60, which corresponds to the sample size of our study.

To achieve the second research objective, the smallest detectable change in the NFR was calculated for our study sample size according to (Hoofs et al., 2017), and it was evaluated whether the effect size exceeded this value. Also, the differences between scores over time were calculated for the variables NFR, LE, personal adjustments, communication strategies, auditory work demands, and self-reported hearing ability. Paired t-tests were used to evaluate differences between T_0 and T_1. Change scores were not calculated for the variables general health condition and the BHI, because the aural rehabilitation was not expected to change these variables. Change scores were also not calculated for the variable 'feeling that something should change at work', since differences in this variable would be difficult to interpret at group level. For example, increased need for change might reflect an unsatisfactory result of the rehabilitation, but might also reflect increased awareness of the impact of work circumstances on the hearing loss complaints. In a secondary analysis, the differences between the subscales from the CPHI were calculated and assessed using paired t-tests.

We performed a post hoc power analysis based on the effect size of NFR. Our sample size would give a power of 74% and 5% significance in a paired mean comparison test.

To identify the factors associated with a decrease in NFR and LE, regression analyses were performed using the change scores (outcome and determinants). Every determinant was used separately in a univariate regression model and hierarchical multiple analyses were performed. For the primary and the secondary outcome measures, the first block consisted of the potential confounders age, gender, educational level, and BHI. In the next blocks, the determinants were added one by one. For each block, we calculated the change in amount of variance.

Data were analyzed using the Statistical Package for Social Sciences (SPSS) version 26.0 (Armonk New York USA). For all tests, the type I error was set to 0.05 and all tests were two-sided.

Results

Table 2 presents comparisons between the correlation coefficients presented by Van der Hoek-Snieders et al. (2020) and the correlation coefficients that were found in the current study. In line with the previous findings, NFR was moderately associated with 'feeling that something should change at work' ($r = .46$, $p < .01$), LE ($r = .54$, $p < .01$), general health condition ($r = .33$, $p = .01$), and personal adjustments ($r = -.37$, $p < .01$).

In accordance with the previous findings, LE was moderately associated with 'feeling that something should change at work' ($r = .46$, $p < .01$), auditory work demands ($r = .58$, $p < .01$), and personal adjustments ($r = -.56$, $p < .01$). A non-significant association was found between LE and the BHI (r = .07, p = .63).

Table 3. Correlations and prediction intervals comparing the correlations found in this study and the correlations found in the previous study by Van der Hoek-Snieders et al. (2020)

	Previous study		**Current study**	
	Correlation	**Prediction interval**	**Correlation**	**Hypothesis confirmed?**
Need for recovery				
Feeling something should change	.48	.27 ; .68	.46	Yes
Subjective listening effort	.53	.34 ; .72	.54	Yes
General health condition	.45	.23 ; .66	.33	Yes
Personal adjustments	-.46	-.71 ; -.20	-.37	Yes
Subjective listening effort				
Feeling something should change	.39	.16 ; .62	.46	Yes
Binaural hearing impairment	.32	.07 ; .56	.07	Yes
Auditory work demands	.41	.18 ; .63	.58	Yes
Personal adjustments	-.44	-.69 ; -.18	-.56	Yes

Table 4 shows the mean scores and standard deviations of the questionnaire scores before and after the aural rehabilitation. Based on a sample size of 60, the smallest detectable change in NFR is 5.77. NFR decreased on average by 6.86.

A significant difference was found for the variables NFR, LE, personal adjustments, SSQ speech, and SSQ spatial. No significant differences were found regarding the variables communication strategies, auditory work demands, and SSQ quality.

Table 4. Paired t-tests of questionnaire scores before and after receiving aural rehabilitation (n = 50)

	Baseline (T_0)	**Follow up (T_1)**	**Difference T_1 - T_0**	***t***	***p***
Need for recovery[a]	51.89 (20.47)	45.03 (21.62)	-6.86 (14.09)	-3.34	<.01
Subjective listening effort[b]	9.90 (3.33)	8.30 (3.72)	-1.60 (3.03)	-3.73	<.01
Personal adjustments[c]	51.59 (12.87)	56.37 (13.66)	4.78 (7.68)	3.27	<.01
Communication strategies[d]	68.17 (9.23)	69.36 (10.00)	1.19 (7.77)	0.99	.33
Auditory work demands[e]	29.38 (6.81)	30.10 (6.81)	0.72 (4.31)	1.18	.24
SSQ speech[f]	5.51 (1.73)	6.16 (1.78)	0.65 (1.39)	2.76	<.01
SSQ spatial[f]	4.46 (2.19)	5.16 (2.28)	0.70 (1.66)	2.56	.02
SSQ quality[f]	6.57 (1.86)	6.91 (1.68)	0.34 (1.40)	1.46	.15

SSQ indicates Speech, Spatial, and Qualities of hearing scale.

[a] Higher score indicates higher level of need for recovery.

[b] Higher score indicates higher level of subjective listening effort.

[c] Higher score indicates more adequate personal adjustments.

[d] Higher score indicates more adequate communication strategies.

[e] Higher score indicates higher auditory work demands.

[f] Higher score indicates greater self-reported hearing ability.

The secondary analysis revealed a significant difference for two of the three personal adjustment subscales, respectively for acceptance of loss and for the subscale stress and withdrawal (Table 5). No significant differences were found in the three communication strategies subscales.

Table 5. Paired t-tests of CPHI subscales before and after receiving aural rehabilitation (n = 50)

	Baseline (T_0)	**Follow up (T_1)**	**Difference T_1 - T_0**	***t***	***p***
Personal adjustments					
Self-acceptance[a]	3.70 (1.04)	3.91 (0.91)	0.21 (0.72)	1.87	.07
Acceptance of loss[a]	3.17 (0.93)	3.62 (1.67)	0.45 (1.32)	2.87	.01
Stress and withdrawal[a]	3.05 (0.88)	3.28 (0.98)	0.23 (0.51)	2.17	.04
Communication strategies					
Maldaptive behavior[a]	4.02 (0.76)	4.07 (0.73)	0.05 (0.53)	0.54	.59
Verbal strategies[a]	2.97 (0.89)	3.09 (0.89)	0.12 (0.76)	1.01	.32
Non-verbal strategies[a]	3.84 (0.96)	3.84 (0.85)	0.00 (0.64)	0.10	.92

SSQ indicates Speech, Spatial, and Qualities of hearing scale.
[a] Higher scores indicate more adequate coping behavior.

In 29 patients, the difference between the NFR score at T0 and T1 was 5.77 or less (Figure 3). In 2 patients, the NFR scores increased more than 5.77. In 16 patients, the NFR score decreased more than 5.77. There were no obvious differences in the improvement in NFR between patients receiving different hearing aid interventions.

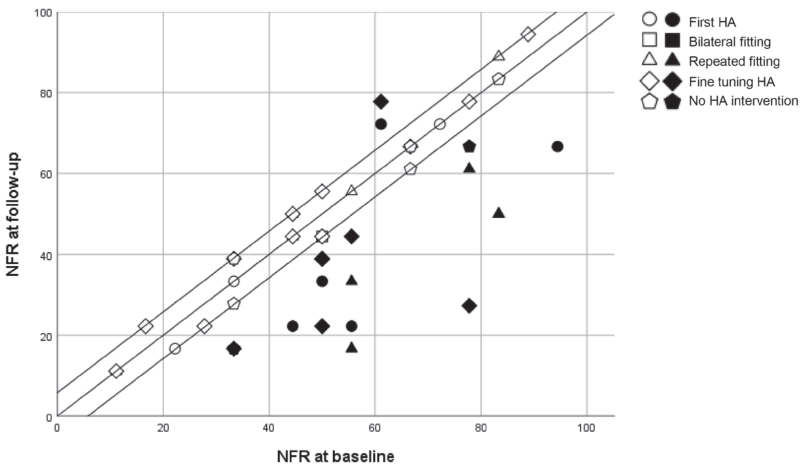


Figure 3. Scatterplot of need for recovery scores at T_0 and T_1 for employees who received different hearing aid interventions. Icons on the diagonal represent need for recovery scores that were exactly the same at T0 and T1. The two other lines show the smallest detectable change of 5.77. The icons are colored in for the employees in which the need for recovery score had changed more than the smallest detectable change. HA indicates Hearing Aid.

In the univariate regression analyses (Table 6), three change scores were found to significantly explain variance in the NFR change score, respectively LE ($p = .03$), personal adjustments ($p < .01$), and SSQ quality ($p < .01$). In the hierarchical regression analyses, the amount of variance changed significantly when the determinants subjective listening effort, personal adjustments, and SSQ quality were added to the model (Table 7). The amount of explained variance was highest when the personal adjustments were added to the model. This model explained 53 percent of the variance in the change in NFR.

All change scores, except for the communication strategies change score, were found to significantly explain variance in the LE change score in the univariate regression analyses, respectively personal adjustments ($p = .04$), auditory work demands ($p = .01$), SSQ speech ($p < .01$), SSQ spatial ($p = .03$), and SSQ quality ($p = .03$). In the hierarchical regression analyses, the amount of variance changed significantly when the SSQ speech was added to the model (Table 7). This model explained 12 percent of the variance in the change in LE.

Table 6. Results of the univariate regression analysis of the factors associated with change in the need for recovery and subjective listening effort

	Determinant	**B**	**95% CI**	***p***	***R^2***
Change in need for recovery	Subjective listening effort	1.40	-9.12 ; -0.19	.03	.10
	Personal adjustments	-1.23	-1.69; -0.78	<.01	.45
	Communication strategies	0.02	-0.56 ; 0.60	.94	.00
	Auditory work demands	-0.01	-0.97 ; 0.99	.98	.00
	SSQ speech	-2.12	-5.21 ; 0.97	.17	.04
	SSQ spatial	-1.95	-4.39 ; 0.85	.14	.06
	SSQ quality	-5.24	-7.82 ; -2.66	< .01	.28
Change in subjective listening effort	Personal adjustments	-0.13	-0.56 ; -0.01	.04	.11
	Communication strategies	-0.11	-0.26 ; 0.02	.09	.07
	Auditory work demands	0.25	0.06 ; 0.44	.01	.12
	SSQ speech	-1.08	-1.70 ; -0.47	<.01	.22
	SSQ spatial	-0.59	-1.12 ; -0.08	.03	.10
	SSQ quality	-0.71	-1.34 ; -0.09	.03	.11

SSQ indicates Speech, Spatial, and Qualities of hearing scale.

Table 7. Results of the hierarchical multiple regression analysis of the factors associated with change in need for recovery and subjective listening effort. The determinants of block 1 were included as potential confounders in the other blocks

	Block	Predictors	R^2	R^2 change[a]	p R^2 change
Change in need for recovery	1	Age Gender Educational level BHI	.03	-	-
	2	Subjective listening effort	.23	.20	<.01
	3	Personal adjustments	.53	.50	<.01
	4	Communication strategies	.04	.01	.55
	5	Auditory work demands	.03	.00	.75
	6	SSQ speech	.15	.12	.05
	7	SSQ spatial	.13	.10	.10
	8	SSQ quality	.38	.30	<.01
Change in subjective listening effort	1	Age Gender Educational level BHI	.06	-	-
	2	Personal adjustments	.15	.10	.05
	3	Communication strategies	.08	.02	.31
	4	Auditory work demands	.12	.06	.09
	5	SSQ speech	.26	.20	<.01
	6	SSQ spatial	.13	.07	.09
	7	SSQ quality	.15	.09	.05

BHI indicates Binaural Hearing Impairment; SSQ, Speech, Spatial, and Qualities of hearing scale.
[a] R^2 change in comparison to block 1

Discussion

The aim of this study was two-fold, respectively to determine whether the model of Van der Hoek-Snieders et al. (2020) could be confirmed regarding the factors influencing the NFR and LE in employees with hearing loss and to identify the factors associated with a decrease in NFR and LE after three months of aural rehabilitation.

Analysis of the baseline data confirmed the relationships in the model of factors influencing the NFR, since all correlation coefficients were consistent with the previous study. Our results therefore support the conceptual premise that higher LE can be an explanation of increased NFR after work (Kramer et al., 2006). However, in agreement with the model, our results suggest that this explanation is not conclusive, and that increased NFR can also partially be explained by the way employees cope with their hearing loss. The hypotheses regarding the outcome LE were also confirmed, but it must be noted that the association with BHI was weak and non-significant. Although employees with hearing loss have been shown to report higher LE compared to those with normal hearing (Kramer et al., 2006), our results do not indicate that differences in the degree of hearing loss can explain the severity of the LE. An explanation is that the degree of hearing loss was moderate in the majority of the study participants. The differences in degree of hearing loss were thus relatively small. Also, the degree of limitations does not only depend on the degree of hearing loss, but also on other factors, such as the auditory work demands or the personal adjustments (Van der Hoek-Snieders et al., 2020). Lastly, the association between the degree of hearing loss and LE would possibly be higher when the degree of hearing loss is measured with a performance test in an aided listening situation. This should be assessed by future research.

Analysis of the questionnaire data before and after the aural rehabilitation revealed significant improvements, both in NFR and in LE. Our study is the first that demonstrates that the NFR of employees with hearing loss can be improved by aural rehabilitation. In previous studies, no significant improvement in NFR was reported after aural rehabilitation (Gussenhoven et al., 2017; Van Leeuwen et al., 2021). An explanation might be that the population of Gussenhoven et al. (2017) included a relatively high number of participants with low NFR, which might have resulted in a floor effect in their study. The mean NFR hardly differs between our study (mean = 50.1, SD = 21.6) and the study of Gussenhoven et al. (2017) (mean = 46, SD = 31). However, employees presented substantially more often with low NFR (NFR score below 20) in the latter study. Specifically, low NFR was found in 8 percent of participants in our study and in 26 percent of the participants in the study of Gussenhoven et al. (2017). The number of employees with low NFR is not mentioned by Van Leeuwen et al. (2021). Differences in follow-up time might also explain the finding that we found a significant reduction in NFR in contrast to earlier studies. Our follow-up time was three months, whereas van Leeuwen et al. (2021) had a follow-up time of five years. It could therefore be the case that NFR decreases directly after the aural rehabilitation, but increases again after some time. A similar pattern was observed in a recent study, including patients that received their first hearing aid (Holman et al., 2021b). Although listening related fatigue decreased from before fitting to six months post-fitting for some of the included patients, no change was observed in long-term general fatigue. This pattern was however not concluded by Gussenhoven et al. (2017) who had a follow-up time of 3, 6, 9, and 12 months, and should be investigated by future research. Differences in the provided intervention between the studies might also explain that we found a significant reduction in NFR in contrast to earlier studies, such as differences in the aural rehabilitation decisions, the type of counselling, and the quality of the technology that was used. Although the aspects of aural rehabilitation that were provided differed between the patients in this study, most patients in our study received a broad intervention including several aspects of aural rehabilitation. For example, instruction or counselling on coping behavior was provided to 31 percent of our study population, to 14 percent of the intervention group of Gussenhoven et al. (2017), and Van Leeuwen et al. (2021) did not assess this aspect of aural rehabilitation. Presumably, instruction or counselling on coping behavior was provided more frequently in our study than in the two previous studies.

Although the mean NFR decreased after the aural rehabilitation, NFR only decreased in approximately one third of the employees. This finding suggests that the current usual practice may not be sufficient to achieve a reduction in NFR in all employees with hearing loss. Therefore, improving current practices should be considered and investigated. Also, there is need for standards or guidelines of hearing health care for employees with hearing loss. For example, the use of questionnaires regarding NFR, LE, and hearing-related coping behavior at baseline seems to be useful and convenient to describe patient's work needs at baseline. However, these questionnaires need to be validated for the use of diagnosing and evaluating the hearing-related difficulties of employees with hearing loss. Also, in our study sample, hearing aid interventions received most attention, whereas the application of assistive listening devices and the use of instruction/counselling was not that often registered. Although this is in line with international practices (Hickson et al., 2013; Kochkin, 2009; Timmer et al., 2015), the great focus on hearing aid interventions might not have resulted in the optimal mix of aural rehabilitation components.

We did not observe obvious differences in the improvement in NFR between patients receiving different hearing aid interventions. Although it would be plausible that the provision of a first hearing aid would have greater impact on NFR than fine tuning hearing aid settings, this appears not to be the case in our study population. This might imply that the effect of hearing aid interventions on NFR might be rather marginal, which is in line with results of Van Leeuwen et al. (2021). Since the follow-up time of three months was relatively short, it might also be the case that the first hearing aid users were not yet used to their hearing aid, which might have suppressed its effect on the NFR. Another explanation is that hearing aids may not always meet the expectations of first hearing aid users. In that case, managing patients expectations on what effects can realistically be expected from hearing aids might improve rehabilitation outcomes. Future studies with greater sample size and longer follow-up time should further assess this matter.

Our regression analysis revealed that change in NFR and LE can best be explained by different factors. Change in NFR could best be explained by change in personal adjustments, whereas change in LE could best be explained by change in self-reported hearing ability. This finding suggests that improved hearing might result in decreased LE, but not automatically in decreased NFR. Especially interventions that affect personal adjustments may be promising to reduce NFR in employees with hearing loss. As suggested in previous studies (Backenroth-Ohsako et al., 2003; Gussenhoven et al., 2017; Van Leeuwen et al., 2021), we therefore hypothesize that greater improvement in NFR might be obtained when sensory management interventions are not provided in isolation, but combined with interventions that foster adequate coping behavior. Future research is required to assess this hypothesis, since no conclusions on causality can be drawn because of the design of this study.

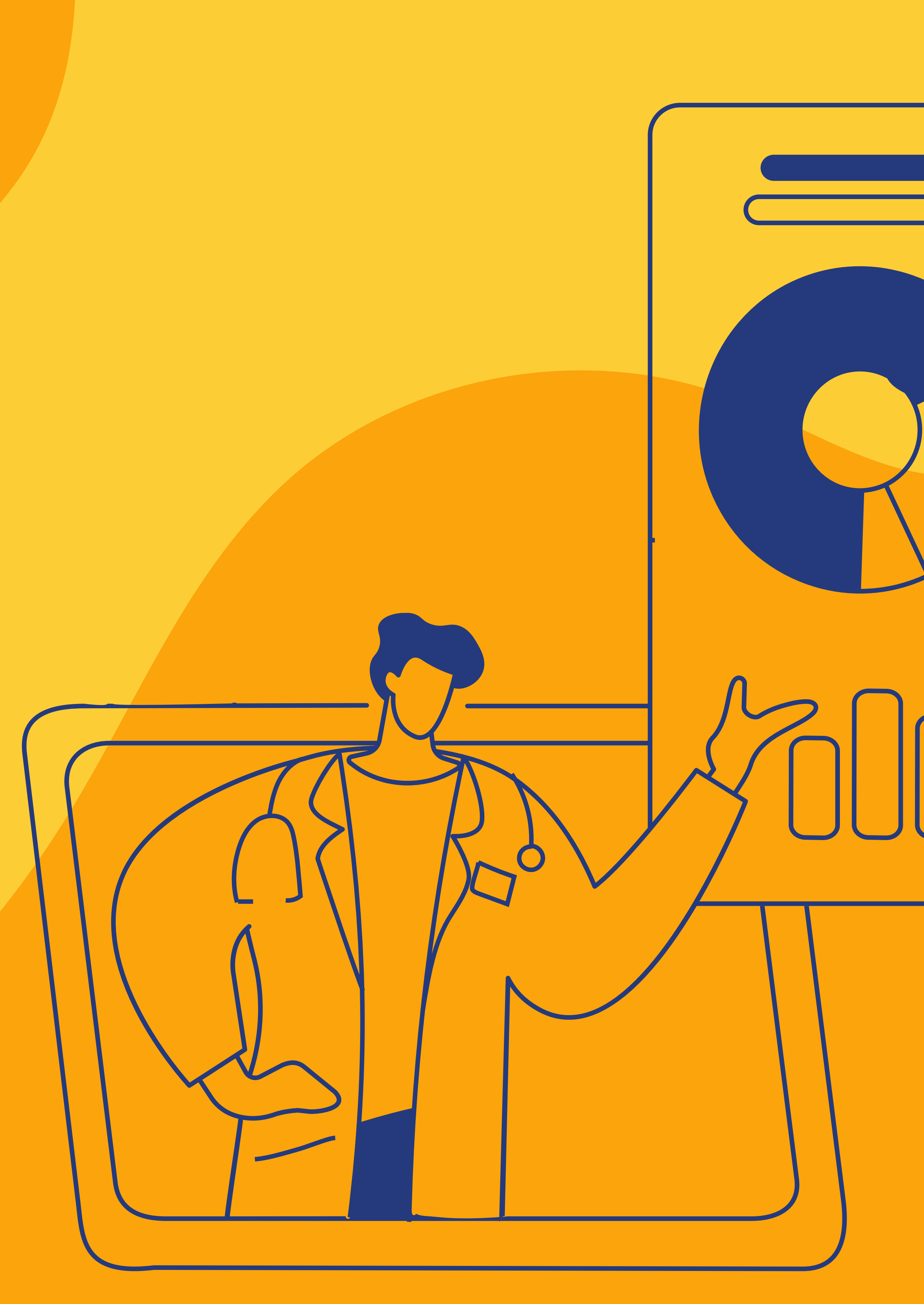
Some strengths and limitations should be noted for this study. Due to a programming error, one SSQ question was not included in the questionnaire. We do not expect that this has had a major impact on the SSQ spatial score, because this scale score is an average score of 7 questions. Also, since the last question was missing, this cannot have influenced the scores of other questions.

This study was performed in the setting of routine clinical practice, which improves the applicability of the results. A downside of our design was that no homogeneous intervention was provided and that there was no control group. Therefore, we cannot conclude that the improvement in NFR can be attributed to (aspects of) the aural rehabilitation. Also, the study population was too small to run subgroup analyses on patients who received the same intervention. The post hoc power analysis that was based on the effect size of NFR revealed that the 80% power was not achieved. This implies that our study might have been slightly underpowered to detect changes in the NFR. Despite this, we found a significant difference in the NFR.

We carefully described the components of aural rehabilitation that were provided using patient files, but we may have missed some aspects of the provided rehabilitation. For example, audiologists of the included audiological centers often give some kind of instruction on how the hearing aids or assistive listening devices function and how they can be properly used. However, this type of instruction was not administered in the patient files, and is therefore not reported in this study. Another study limitation is that the follow-up time of this study was relatively short. Aural rehabilitation was provided within this period in most, but not in all patients, which resulted in the exclusion of a few patients. An advantage of the follow-up time of three months is that there is a smaller chance that the NFR has changed due to other reasons than the aural rehabilitation.

Concluding remarks

The NFR and LE of employees with hearing loss can be improved by aural rehabilitation, but this study shows that this is true in only part of the employees. Therefore, improving current practices should be considered and evaluated, for example by applying a different combination of rehabilitation components. Especially, interventions that affect personal adjustments may be promising to further reduce the NFR in employees with hearing loss.



Chapter 4

Communication strategies, personal adjustments, and need for recovery in employees with hearing loss who receive a communication group-training

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Abstract

Purpose

Communication group-trainings are part of current aural rehabilitation practices, but their effect have not yet been investigated systematically in working adults. The purpose of this study was to describe the communication strategies, personal adjustments, and need for recovery of employees with hearing loss before and directly after a communication group-training.

Methods

Nine employees were included at two audiological centers that provided a different group-training. Two online questionnaires were completed, at baseline and after completing the training.

Results

Most employees used more adequate communication strategies after the group-training, but there seems to be a difference between the improvement in personal adjustments between the centers. No trends towards a decrease in need for recovery was observed.

Conclusion

It is still challenging to reduce the work-difficulties that are encountered by employees with hearing loss. The inter-center differences point out to a need for standardization. Suggestions for improvements are provided and should be further investigated in a larger population.

Introduction

Hearing loss in the working population affects work functioning (Backenroth-Ohsako et al., 2003; Granberg & Gustafsson, 2021). It causes hearing and communication difficulties, for example during group-meetings or in noisy/reverberant workplaces. In an attempt to overcome these difficulties, different coping strategies can be used (Barker et al., 2017; Christensen & Gupta, 2017). Employees with hearing loss often put extra effort and concentration when listening, use assistive listening devices, inform their colleagues about the hearing loss, or withdraw from difficult working situations. Although some of these strategies might be effective to reduce the hearing and communication difficulties at the workplace, not all of the difficulties can be compensated for (Jennings & Shaw, 2008). The benefit of assistive listening devices is smaller in noisy environments (Lesica, 2018) and it can be demanding and fatiguing to continuously put extra effort and concentration when listening at work (Holman et al., 2021a). Moreover, communication difficulties can result in the inability to complete work tasks, making mistakes in work (Granberg & Gustafsson, 2021), and feelings of stress, frustration, and incompetency (Hasson et al., 2011; Hua et al., 2015; Tye-Murray et al., 2009).

A great amount of evidence regarding the impact of hearing loss on the employment status has recently been summarized in a systematic review (Shan et al., 2020) and a scoping review (Granberg & Gustafsson, 2021). Compared to those with normal hearing, employees with hearing loss are more likely to earn less, to take more sick leave, to become unemployed or partly unemployed, and to take earlier retirement. Therefore, there lies great social and economic importance in good rehabilitation services for employees with hearing loss.

It is increasingly acknowledged that aural rehabilitation services for employees with hearing loss require a multidimensional approach, because of the interplay between hearing loss, personal factors, and work characteristics (Granberg & Gustafsson, 2021; Zuriekat et al., 2021). However, the focus of current practices is often on technical interventions, rather than on perceptual training or counselling services on how to cope with hearing loss at work (Granberg & Gustafsson, 2021; Zuriekat et al., 2021). A reason might be that rehabilitation services for employees with hearing loss are not standardized and poorly documented (Granberg & Gustafsson, 2021; Gussenhoven et al., 2013). For example, it is unclear what interventions can best be provided individually or in a group-setting, what the duration and intensity of counselling should be, and what tools should be used to describe and evaluate the effects of rehabilitation services on work functioning in employees with hearing loss.

The outcome Need For Recovery (NFR) has been suggested to be a valuable tool for evaluating the effects of aural rehabilitation services in employees with hearing loss, because of its predictive value of occupational or health problems (Danermark & Gellerstedt, 2004; De Croon et al., 2003; Mohr et al., 2000; Nachtegaal et al., 2012; Sluiter et al., 2003). NFR is a generic outcome measure that represent the need to recuperate from work-induced fatigue (Van Veldhoven et al., 2015). It is a multidimensional construct that is influenced by personal and work-related factors, such as coping-behavior (Machin & Hoare, 2008) and work demands (Sonnentag & Zijlstra, 2006). Specifically for employees with hearing loss, hearing-related coping behavior was shown to be associated with the NFR (Van der Hoek-Snieders et al., 2020).

So far, three studies evaluated the effect of aural rehabilitation services on the NFR of employees with hearing loss (Gussenhoven et al., 2017; Van der Hoek-Snieders et al., 2022; Van Leeuwen et al., 2021). One study did assess the effect of hearing aid uptake only (Van Leeuwen et al., 2021) and the other two studies assessed a multidimensional approach. An individual speech reading training was incidentally offered (Van der Hoek-Snieders et al., 2022) and individual counselling was offered in 14 percent (Gussenhoven et al., 2017) and 31 percent of the included employees (Van der Hoek-Snieders et al., 2022). A positive effect on the NFR was only reported in the last study. It was concluded that the NFR can be improved by aural rehabilitation, although this was only the case in part of the employees. An analysis of the change scores that were associated with change in the NFR revealed that especially interventions that affect personal adjustments (PA) may be promising to reduce the NFR. PA are part of the hearing-related coping behavior and include self-acceptance, acceptance of hearing loss, and having little stress and withdrawal.

Instruction or counselling on coping behavior can also be provided in a group-setting of a communication training. This training includes a speech reading training and instruction or counselling on effective communication strategies (CS) and PA. A group-training might be more effective than individually tailored instruction or counselling, because usually, it takes more time to participate in a group training ('higher dose of the intervention') and a group training provides the opportunity to interact with other employees with hearing loss and share experiences (Hawkins, 2005). This training is part of the routine clinical practice of most Dutch audiological centers. In some centers, the communication group-training is provided in separate groups for employees with hearing loss. In other centers, employees with hearing loss participate in this training together with non-working adults. The effects communication trainings on the CS, PA, and NFR of employees with hearing loss have not yet been investigated. Therefore, the aim of this study is to describe the CS, PA and NFR in a small sample of employees with hearing loss before and directly after participating in a communication group-training.

Materials and methods

Study design

This study focused on employees with hearing loss who received a communication group-training in the period from October 2020 to January 2022. To provide a broad description of current practices, employees were included at two audiological centers in the Netherlands, respectively Libra Revalidation and Audiology (AC1) and Adelante Audiology and Communication (AC2). Outcomes were measured by an online questionnaire before the start of the training (T_0) and directly after the last meeting of the training (T_1). The time interval between T_0 and T_1 ranged from 7 to 12 weeks.

Ethical considerations

All procedures were done in accord with the Declaration of Helsinki of 1964 and its later amendments. The Ethics Committee of the Academic Medical center declared that no formal approval of the detailed protocol was required according to the Dutch Medical Research Involving Human Subjects Act (No. W19_501).

Participants

Eligible employees participated in the communication group-training of AC1 between 2020 and 2022 or in the communication group-training of AC2 between 2021 and 2022. The inclusion criteria further required the employees to be aged between 18 and 67, to work at least 8 hours per week, to have hearing complaints in the work situation, and to complete the informed consent form and both questionnaires.

Communication training

The content of the communication group-training at AC1 and AC2 is summarized in Table 1. The training consists of a speech reading training, instruction about hearing loss, instruction about assistive listening devices, and instruction or counselling on daily life situations. The communication training is mainly provided by a social worker and a speech therapist. A PowerPoint presentation is used to display program information and to provide information during the instructions. One session is partly facilitated by an audiologist who provides instruction about hearing loss and technical devices. During breaks and plenary discussions, interaction between participants is encouraged.

AC1

The training in AC1 consists of 6 meetings. Per group, 5 to 6 participants can participate together with their significant others (often their spouse). The participants can be both working or non-working. Only working adults were included in this study. In every session, the speech reading training and counselling are provided. The counselling focuses on the themes psychological defense responses (fight, flight, freeze) and communication strategies. The participants are encouraged to reflect on their communication needs and to use CS in their personal lives. At AC1, videos have been made of people coping with hearing loss in different social situations. After watching a video, the strategies that were used are discussed and related to the personal situation of the participants. Participants can also introduce difficulties that they encounter in their personal lives. During one session, the *Hoorinfotheek* is visited. This is a center that provides information and advices about assistive listening devices, including external microphones, wake-up systems, induction loops, and wireless headphones.

AC2

The communication training in AC2 consists of 11 meetings of 120 minutes each. Per group, 3 or 4 participants can take part together with their significant others. Employees participate in groups that include working participants only.

Before the first meeting, an individual session takes place to prepare the employee for the communication training. Another individual session takes place three months after the last meeting to evaluate the training. This evaluative session thus took place after T_1.

In every session, the speech reading training and counselling are provided. Counselling focuses on personal and work situations. Employees are encouraged to reflect on their communication needs, to use CS, and to make PA in personal and work situations. Different personal and work situations are discussed and employees are encouraged to introduce difficulties that they encounter in their personal or work lives. The counselling focuses on the themes empowerment, demands and capacities, the complexity of communication, hearing loss and relationships, and acceptance of the hearing loss.

Table 1. Characteristics and content of the communication group-training at the two participating audiological centers (AC1 and AC2)

	AC1	AC2	Provided by
Duration course	10,5 hours	22 hours	-
Working participants only	No	Yes	-
Speech reading training	45%	30%	Speech therapist
Instruction about hearing loss	12%	20%	Audiologist
Instruction about technical devices	10%	10%	Audiologist
Counselling on personal situations	33%	20%	Social worker
Counselling on work situations	0%	20%	Social worker

AC indicates Audiological Center.

Baseline characteristics

The following variables were used to describe the study characteristics at baseline: gender, age, educational level, work sector, duration of the hearing impairment, use of hearing aids, and the degree of the hearing loss. The degree of hearing loss was derived from the patient files and was described as the mean pure-tone average at 1000, 2000 and 4000 Hz, averaged across ears with a five to one weighting favoring the better ear (binaural hearing impairment, BHI).

Subjective listening effort (listening effort) and auditory work demands were assessed using the Amsterdam Checklist for Hearing and Work. This checklist assesses the occurrence of six hearing-related job activities (to detect sounds, to distinguish sounds, to communicate in quiet, to communicate in noise, to localize sounds, and to be exposed to loud sounds) and the effort that these activities take. We calculated a sum score of these six questions. The listening effort score can vary between 0 and 18 and the auditory demands score can vary between 0 and 48. Higher scores represent more listening effort and/or higher auditory work demands.

Outcome measures

Communication strategies & personal adjustments

CS and PA were assessed using the CPHI (Lidwine B. Mokkink et al., 2010). The domain CS consists of the scales maladaptive behavior, verbal coping, and non-verbal coping. Questions include communication strategies that can be used to cope with hearing loss, such as to dominate conversations (maladaptive behavior), to ask for a repeat twice (verbal coping), and to watch person's face (non-verbal coping). The domain PA consists of the scales self-acceptance, acceptance of hearing loss, and stress and withdrawal. Questions include feelings, attitudes, and self-concept that have an effect on interpersonal relationships, such as to feel embarrassed to ask for repeat (self-acceptance), to have difficulties to admit the hearing problem to others (acceptance of hearing loss), and to withdraw from social talks because of hearing loss (stress and withdrawal). Responses are given on a 5-point scale and the scores for CS and PA consist of the sum score of the scales. Higher scores represent more adequate CS and PA.

Need For Recovery

We assessed the NFR using the NFR scale from the Questionnaire on the Experience and Evaluation of Work 2.0 (QEEW 2.0) (Van Veldhoven et al., 2015). This scale includes six statements with four response categories that assess indicators of fatigue, such as reduced concentration or feeling exhausted at the end of a working day. The sum score is converted to a scale score (percentage of the maximum score) that ranges from 0 to 100, with a higher score denoting higher levels of NFR.

Statistical analysis

Descriptive data are provided of the measurements at T_0 and T_1 at case level. Change scores are calculated and visualized in scatterplots. For employees of both AC's, we present median scores and the range of the change scores.

Results

At AC1, 4 employees of 3 different training groups were eligible for inclusion. They all completed the questionnaire at T_0 and T_1. At AC2, 9 employees of 3 different training groups were eligible for inclusion. Of these employees, 4 were excluded, because the follow-up questionnaire was not completed. The other 5 employees completed the questionnaire at T_0 and T_1. The baseline characteristics are presented in Table 2. The employees, 6 females and 3 males, were aged between 49 and 64 and work 20 to 60 hours per week in various professions. Their degree of hearing loss was mild to moderate and except for one employee, they were all hearing aid users.

Table 2. Baseline characteristics of the included employees at two audiological centers (AC1 and AC2)

	Age	Gender	BHI in dB HL	Hearing loss since	Hearing aids	Educational level	Profession	Working hours per week	Auditory work demands	Listening effort
AC1										
	58	female	37.2	6-10 years	yes	University	Team leader	32	15	13
	58	male	56.6	6-10 years	yes	General secondary	Entrepreneur	60	18	17
	52	male	55.0	2-5 years	yes	General secondary	Draftsman	32	9	10
	64	female	44.1	>10 years	yes	Intermediate vocational	Harvest worker	20	18	15
AC2										
	50	female	59.4	2-5 years	yes	Higher vocational	HR employee	36	15	9
	59	female	56.4	>10 years	yes	Intermediate vocational	Doctor's assistant	28	20	14
	58	male	38.6	0-1 year	no	General intermediate	Mason	40	14	5
	49	female	45.0	>10 years	yes	General secondary	Admin. assisstant	32	10	8
	56	female	45.3	6-10 years	yes	University	Nurse	40	19	10

BHI indicates Binaural Hearing Impairment and is calculated by averaging the pure-tone thresholds at 1000, 2000, and 4000 Hz favoring the better ear.

Table 3. Questionnaire scores and benefits in the communication strategies, personal adjustments, and need for recovery before (T_0) and after (T_1) participating in a communication group-training

	Communication strategies			Personal adjustments			Need for recovery		
	T_0	T_1	Change score	T_0	T_1	Change score	T_0	T_1	Change score
AC1		AC1							
	68	75	7*	46	58	12*	44	50	6
	70	64	-6	40	35	-5	33	33	0
	60	62	2*	51	50	-1	50	39	-11*
	50	62	12*	29	32	3*	39	67	28
AC2		AC2							
	52	66	14*	52	56	4*	72	61	-11*
	45	61	16*	23	47	24*	61	39	-22*
	38	63	25*	39	38	-1	44	78	34
	55	56	1*	37	54	17*	44	33	-11*
	58	76	18*	46	59	13*	39	39	0

* Compared to the score at T0, a more favorable score was obtained at T1

The outcomes are summarized in Table 3, Figure 1, and Figure 2. Without considering clinical or statistical significance, the CS score was more favorable after the communication training in 3 of the 4 employees of AC1 and in all employees of AC2. Change scores ranged from -6 to 12 at AC1 and from 1 to 25 at AC2 (positive change scores represent improvement).

A more favorable PA score was observed in 2 of the 5 employees of AC1 and in 4 of the 5 employees of AC2. Change scores ranged from -5 to 12 at AC 1 and from -1 to 24 at AC2 (positive change scores represent improvement).

The NFR score was more favorable in 1 of the 4 employees of AC1 and in 3 of the 5 employees of AC2. Change scores ranged from -11 to 28 at AC1 and from -22 to 34 at AC2 (negative change scores represent improvement).

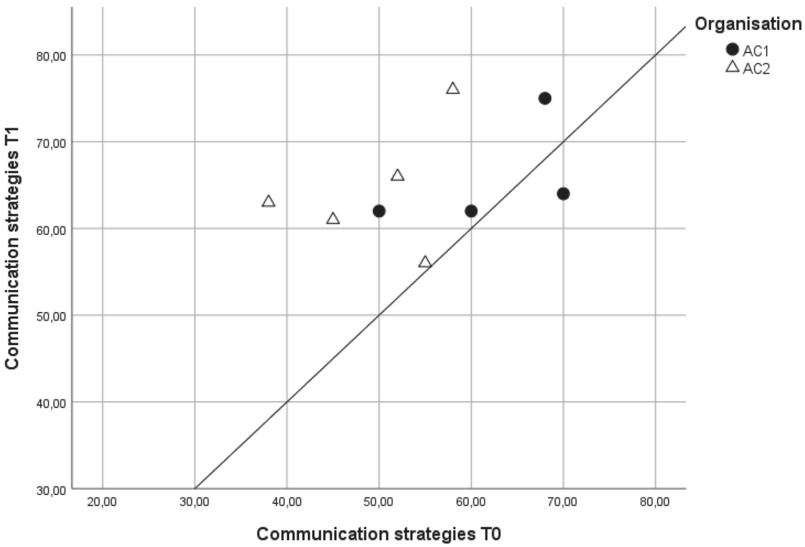

Figure 1. Scatterplot of the communication strategies scores before (T_0) and directly after (T_1) a communication group-training at AC1 (*n* = 4) and AC2 (*n* = 5). Dots above the diagonal represent improvement in the communication strategies

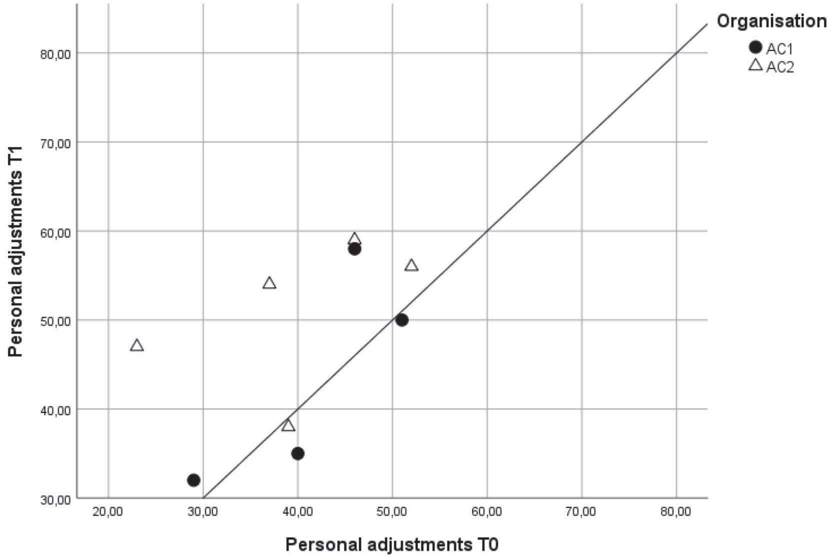

Figure 2. Scatterplot of the personal adjustments scores at before (T_0) and directly after (T_1) the communication training at AC1 (*n* = 4) and AC2 (*n* = 5). Dots above the diagonal represent improvement in personal adjustments

Discussion

The aim of this study was to describe the CS, PA, and NFR of employees with hearing loss before (T_0) and directly after (T_1) participating in a communication group-training. The results suggest that most employees used more adequate CS after the group training and that their PA remained relatively stable or improved. There seems to be a difference between the two centers. For both centers, no clear trend towards a decrease in the NFR was observed.

The improvement that was observed regarding the CS is in line with the systematic review that concluded that a communication group-training potentially provides better use of CS in (non-working and/or working) adults (Hawkins, 2005). However, this finding contrasts to the results of earlier studies that investigated the effect of aural rehabilitation strategies in employees with hearing loss (Gussenhoven et al., 2017; Van der Hoek-Snieders et al., 2022). This difference is likely to be explained by the differences between the provided interventions. In contrast to the earlier studies (Gussenhoven et al. 2017; Van der Hoek-Snieders et al. 2022), during a substantial part of the trainings described in our study, employees were encouraged to reflect on their communication needs and encouraged to use CS in their lives. Also, although the intensity of the counseling was not described in these earlier studies, it can be assumed that this intensity was lower than in the current study. Therefore, our results suggests that a communication group-training might be effective for improving the CS used by employees with hearing loss.

Regarding the PA, the scores remained relatively stable or improved, although there seems to be a slight difference between the two centers. The PA score of a greater number of employees improved at AC2 compared to AC1 and the improvement accomplished was also greater at AC2. The PA change scores differed from -5 to 12 at AC1 and from -1 to 24 at AC2 with positive scores representing improvement. Especially the change scores of the employees at AC2 seem to be higher than the mean improvement of 4.78 that was reported in a previous study evaluating the effect of aural rehabilitation strategies, including sensory management interventions, perceptual training, and/or individual instruction or counselling (Van der Hoek-Snieders et al., 2022).

The difference between the two centers in the effect of the communication group-training on PA might be explained by differences in the contents of the trainings. The training of AC2 is more intensive than the training of AC1, respectively 22 hours versus 10.5 hours. Also, the individual sessions of AC2 before and after the group training do not take place at AC1. Another difference lies in the homogeneity of the participants. At AC1, employees participated in the training together with non-working participants, often elderly, whereas at AC2 only employees participated. Lastly, the counselling focused on PA themes at AC2, such as acceptance of the hearing loss and empowerment, whereas this focus was less strong at AC1. Our results suggest that greater improvement in PA might be achieved with a higher training intensity, including only participants that have a job, and including counselling that specifically focuses in PA themes, such as empowerment and acceptance of the hearing loss.

For the employees of both centers, no trend towards a decrease in the NFR was observed. This might imply that the NFR of employees with hearing loss does not improve after a communication group-training. Although the sample size of our study was too small to rule out a true effect, our study adds to the body of evidence that current rehabilitation strategies might fail to reduce the difficulties encountered at work by most employees with hearing loss (Gussenhoven et al., 2017; Jennings

& Shaw, 2008; Van der Hoek-Snieders et al., 2022; Van Leeuwen et al., 2021). Potentially, a greater effect on the NFR might be accomplished when there is more focus on work adjustments, such as improving room acoustics and adjusting work schedules. There is a great need for standards or guidelines describing appropriate rehabilitation services supporting employees with hearing loss.

Although we believe that employees with hearing loss might benefit from a communication group-training, suggestions can be given that might improve current practices. First, we suggest to include a thorough assessment of the impact of hearing loss on work performance in the diagnosis of employees with hearing loss. The NFR scale, CPHI, and the Amsterdam Checklist for Hearing and Work might be helpful, although these instruments need to be validated in a population of employees with hearing loss (Van der Hoek-Snieders et al., 2022). Also, making accommodations in the workplace has been described to be a complex and ongoing process that requires conscious attention and effort (Shaw et al., 2013). Therefore, we suggest that employees are supported to start or continue an ongoing dialogue with their employer and colleagues about the challenges that they encounter at work and the strategies that might be helpful. A group-setting might be appropriate for this purpose. The employees in this study were encouraged to bring their significant others, but might also be specifically encouraged to bring their employer and/or their colleagues. Also, the effect of a communication group-training might be greater if the duration is longer than 6 or 11 weeks or if a group-training is followed by individual counselling sessions. This should be investigated by future research in larger samples of employees with hearing loss.

Besides the need for improving current rehabilitation services, the accessibility of multidimensional services is also under pressure. We found that only 13 employees were eligible for inclusion in a period of 15 months which shows that a communication group-training has not been common practice for employees with hearing loss at the two included centers. This might be an effect of the COVID-19 pandemic, since most group-trainings were cancelled or delayed. However, in line with two earlier Dutch studies that reported that counselling services were only provided to a minority of the employees with hearing loss (Gussenhoven et al., 2017; Van der Hoek-Snieders et al., 2022), our finding might also reflect that a multidimensional approach including counselling is not commonly provided to employees with hearing loss, at least not in a group setting.

In conclusion, the results show that it is still challenging to effectively reduce the work-difficulties that are encountered by employees with hearing loss. Especially with regard to the PA, differences between the centers were observed, which points out to a need of standards or guidelines for appropriate rehabilitation services supporting employees with hearing loss. Suggestions for improvement are provided and should be investigated by future research in a larger population.

Part III

Measuring hearing-critical job tasks

Chapter 5

Detectability of auditory warning signals in the ambient noise of Dutch train cabins

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Abstract

Locomotive engineers need to detect auditory warning signals for safe and effective job performance. We measured the levels and spectra of the warning signals and noises present in Dutch train cabins to evaluate the effectiveness of these signals. Audio-recordings were made in six train types during normal operation. Signal detectability was estimated using the Detectsound software and compared against ISO 7731. Signal detectability was also measured in six normally-hearing individuals in a laboratory setting. Signal levels ranged between 68 and 84 dBA. Noise levels ranged between 53 and 77 dBA. The acoustical requirements for signal detectability were not met in multiple driving conditions, especially at higher speed. Sufficient signal-to-noise ratios were achieved in the laboratory measurements, but difficulties can be expected in unfavourable driving situations or when the engineer suffers from hearing loss. Acoustical, environmental, or work modifications might be required to prevent situations with insufficient audibility in hearing-impaired engineers.

Introduction

In many occupations, employees fulfil auditory tasks, such as speech communication and sound detection (Semeraro et al., 2015). This can be very challenging in some working settings, for example when high noise levels are present (Giguère et al., 2008). For locomotive engineers (train drivers), speech communication and sound detection are important for safe and effective job performance (Zoer et al., 2014). An engineer needs to communicate to the signaller, conductor, and others by answering calls, making announcements, and using communication equipment. Detection of warning signals is required to be warned in case of events that can compromise safety (Zheng et al., 2007). The signals aim to alert the driver at passing a sign and to verify whether the engineer is still alert for safe driving (Fenner, 2002; Scaccabarozzi et al., 2017). In Dutch train cabins, the Automatic Train Protection (ATP) system applies a bell-like signal combined with a warning light in the console in case of failure to stop for a stop signal, failure to reduce speed at a caution signal, or failure to comply to the local speed limit. The Driver's Safety Device (DSD), also known as 'the dead man's switch,' produces a buzzer-type auditory warning and is a failsafe in case the driver becomes incapacitated.

Earlier, the appropriateness of the sound environment of Dutch locomotive cabins for speech communication was assessed, using the Speech Transmission Index (STI) (Houben et al., 2007). The STI values were 0.69 for communication using a transceiver and 0.76 for communication using a mobile phone, exceeding the value of 0.5 that is required for acceptable speech communication. It was concluded that the working environment of Dutch locomotive cabins meets the acoustic standards for speech communication. The appropriateness of the acoustic environment of Dutch locomotive cabins for warning signal detection has not yet been investigated, despite its importance for safe and effective job performance. Failure to detect the warning signals will result in decreased safety and decreased operational effectiveness (Merat et al., 2002; Semeraro et al., 2015). If the DSD or ATP signal is missed, the emergency breaking system will automatically reduce speed or bring the train to a full stop.

To guarantee that a locomotive engineer is capable of performing the required auditory tasks, pure- tone audiometry is applied prior to employment as well as on a periodical basis (Tufts et al., 2009). In this study, normal hearing is defined as having hearing thresholds between 1000 Hz and 4000 Hz below 25 dB HL, because an engineer passes the hearing screening without being referred for additional hearing assessments when hearing thresholds are measured at 25 dB HL or lower on the frequencies 1000, 2000, and 4000 Hz at the better ear. When a driver passes the hearing screening, sufficient hearing for safe and effective job performance is concluded. It is thus assumed that train drivers with hearing thresholds below 25 dB Hearing Level (HL) are capable of signal detection in the train cabin. This assumption has not yet been validated.

To evaluate the detectability of warning signals in a specific work-setting, the signal level should be taken into account (Edworthy, 1994; Giguère et al., 2008). If the signal level is too low, the warning signal cannot attract proper attention. According to ISO 7731, a warning signal level is advised to be at least 65 dBA to ensure audibility (ISO, 2003). If the level is too high, the sound can be distracting, can hinder speech communication, or even can cause startle reactions (Edworthy, 1994; Giguère et al., 2008). ISO 7731 therefore states that the maximum sound level of a warning signal should not exceed 118 dBA (ISO, 2003). Additionally, the background noise at each workplace should be taken into account, including the level, spectrum, and type of the noise (Edworthy, 1994; Giguère et al., 2008). A train cabin is a noisy working environment with A-weighted estimated noise levels between 70 and 93 dBA (Lie et al., 2013; Peng et al., 2019). Driving speed can influence the ambient noise level, since the overall exterior sound emission increases with driving speed and several of the internal noise sources depend on driving speed, such as the motor and cooling ventilator (Kurze et al., 2000; Pronello, 2003). Noise levels have been shown to differ between Italian train types (Pronello, 2003), but this has not yet been investigated for Dutch trains. Furthermore, it is unknown if the effect of driving speed on the noise level is similar in different train types.

Computerised tools have been developed to model the expected signal detectability in a specific work setting (Giguère et al., 2008). These models are often based on masked thresholds, defined as the signal level that is just detectible in the presence of the workplace noise (Giguère et al., 2008; Zheng et al., 2007). In accordance with ISO 7731, a signal level of 10–15 dB above masked threshold has been proposed to warrant signal detectability (ISO, 2003; Laroche et al., 1992). There is no model available yet that computes the detectability of the warning signal in the work situation of Dutch locomotive engineers. We therefore aim to specify the acoustic characteristics of the warning signals and the noise levels present in Dutch train cabins and to evaluate the effectiveness of these warning signals when presented to normally-hearing locomotive engineers.

Materials and methods

This study comprises a cross-sectional and observational design. Acoustical measures were carried out to obtain the level and spectrum of the warning signals and the ambient noise in different Dutch locomotive cabins.

Setting

The measurements took place from April 2006 to March 2007. Six types of trains were included, specifically: *Materieel64* (Mat'64), *Locomotief1800* (Loc1800), Sprinter, *Motorrijtuig DubbelDeks Materieel* (mDDm), *InterCity Materieel* (ICM), and *Verlengd InterRegio Materieel* (V-IRM). All trains had electric engines and were exclusively used for conveyance of passengers. For each train type, measurements were performed in two or three different trains with a different locomotive engineer operating within the standard schedule. To avoid possible bias of too low or too high accelerations, the engineers were told that the sound measurements would be used to investigate the audibility of warning signals and not to judge their driving skills or sound exposure. The railroad tracks were selected to be representative for the Netherlands and thus did not contain hills. The train speed at which was measured depended on the railroad tracks that were selected. Since the highest noise levels were expected at maximum speed, at least two measurements were performed at maximum speed in each of the train types. The maximum speed is 120 kilometres per hour (km/h) in the Sprinter and V-IRM, and 130 km/h in the other trains. The measurements were performed under dry weather conditions with a maximum wind speed of 35 km/h.

Acoustical measurements

The acoustical data were collected by sound recordings on digital tape. The on-site measurement set-up consisted of a calibrated sound level meter (B&K 2260 SLM with calibrator B&K 4230) connected to a portable Digital Audio Tape (DAT)-recorder (Tascam DAP). Prior, during, and after the on-site measurements, the recording system was calibrated and checked with a B&K Sound Calibrator Type 4231. The level of the calibration tone was recorded on the Tascam DAT recorder in the same way as the real measurements were made. This recorded calibration-tone was then used to determine the correct level of the DAT recordings during the off-line analysis. The acoustical data were digitally transferred to a computer that was connected to an Echo Gina 24/96 sound card. A-weighting and octave band filtering were applied in compliance with respectively IEC 61260 Class 1 and IEC 61260 (Couvreur, 1997). The DSD and ATP signals were measured in all trains. If adjustable, the volume setting of the warning signal was set at maximum. The DSD signal was measured in quiet. The ATP signal does not occur in quiet and was therefore measured at the lowest speed at which the signal occurs. Unlike the DSD, the ATP signal decays over time. The ATP recordings were therefore averaged over the first 200 milliseconds after onset. This duration roughly corresponds to the human integration time for tonal signals (Viemeister, 1996).

Laboratory measurements

Six subjects (one male; five females) took part in the laboratory measurements. The detectability of the DSD and ATP signal was assessed in the ambient noise of six train types. All participants had normal hearing, defined by pure-tone detection thresholds from 250 to 8000 Hz via air conduction below 25 dB HL. Prior to taking part in the study, informed consent was provided.

A stepwise two-alternative forced choice adaptive approach was used to determine the Signal-to-Noise Ratio (SNR) at which 50 percent of the warning signals can be detected. We will refer to this outcome measure as the SNR_{50}. The noise level was fixed at a presentation level that corresponds with the real-live noise level at the train's maximum speed. The signal level varied and started at a level of 30 dB Sound Pressure Level (SPL) above the expected SNR_{50}. After each correct response, the signal level decreased with a step size of 4 dB SPL until the individual failed to detect the signal correctly. Then, the signal level increased again and followed a one-up one-down procedure with a 2 dB stepsize. The test was continued until five reversals were obtained. The test was programmed in Matlab (The Mathworks, 2005).

The detection test was performed in a sound-isolated booth in a free field setting. The individual was sitting in a chair in the middle of the booth and was surrounded by six omnidirectional speakers at 0, 45, 80, 180, 280, and 315 degrees, and a subwoofer. All subjects were instructed to push the button when a signal was heard, even if the signal was very soft. All individuals completed the test twelve times, since the SNR_{50} was determined for the DSD and ATP signal separately in the ambient noises of six train types. The testing order of the noises and warning signals was counterbalanced across subjects.

Statistical analyses

The acoustical measurements were analysed in in Matlab with the Statistical Toolbox (The Mathworks, 2005) and with Statistica (StatSoft, 2009). Descriptive statistics were calculated for the level and spectrum of the warning signals and the noise field, as well as for the laboratory measurements. For all train types, octave band spectra in dB SPL as well as the A-weighted equivalent sound pressure level in dBA (L_{Aeq}) were presented when driving 80 km/h, 100 km/h and when driving at maximum speed. Differences in ambient noise levels between the train types were investigated using a repeated measures analysis with train type, driving speed, and the interaction between train type and driving speed as independent variables. This analysis was performed with the Statistical Package for Social Sciences (SPSS) version 25.0 (Armonk New York USA).

The detectability of the DSD and ATP signal was estimated with the Detectsound software (Zheng et al., 2003) that has been developed to evaluate the efficacy of auditory warning signals in noisy workplaces (Laroche et al., 1991). Using this software, the detectability of acoustic warning signals in real-life conditions can be predicted. A validation study has revealed that the mean error in estimating detection thresholds in continuous noise fields is typically within 1 dB with a standard deviation of less than 2.5 dB (Zheng et al., 2007). To run Detectsound, the acoustic characteristics of the ambient noise at the workplaces and the warning signals should be obtained in 1/3 octave band levels from 125 to 12500 Hz (Laroche et al., 1991). Warning-signal detectability is predicted for each workplace by comparing the spectral content of the warning signal with the predicted optimal range, also known as 'the design window.' Therefore, the masked detection threshold is calculated according to the acoustical characteristics of the noise and the hearing status of the receivers (Proulx et al., 1996; Zheng et al., 2003). In ISO 7731, a signal level is proposed of 10–15 dB above the masked threshold, and a warning signal is advised to have signal components in the range of 500–2500 Hz (ISO, 2003). In line with these recommendations, the lower and upper limit of the design window are respectively 12 and 25 dB above the masked detection threshold for the detection of the warning sound in the given noise field in frequencies ranging from 125 to 3150 Hz (Zheng et al., 2003). In ISO 7731, it is proposed that at least one spectral component should reach the design window (ISO, 2003), but several authors have suggested that more than one component is required to account for the common fluctuations in background noise of many workplaces (Hung & Hétu, 1996; Laroche et al., 1999; Patterson, 1990; Zheng et al., 2007). The advised number of spectral components required varies from three to four. We consider the spectral requirements for audibility met, when the warning signal has a minimum of three spectral elements (spectral levels measured in 1/3 octave bands) within the design window.

Results

Descriptives

Warning signals

An overview of the level and spectrum of the DSD and ATP signal is presented in Figure 1. The L_{Aeq} varies between the train types from 71.7 to 84.2 dBA for the DSD signal and from 68.2 dBA to 81.5 dBA for the ATP signal. The level of the DSD signal remains relatively constant over time, whereas the level of the ATP signal decreases (Figure 2). The high frequency components of the ATP signal are about 4.5 dB higher at onset than the average level that was used in the calculations.

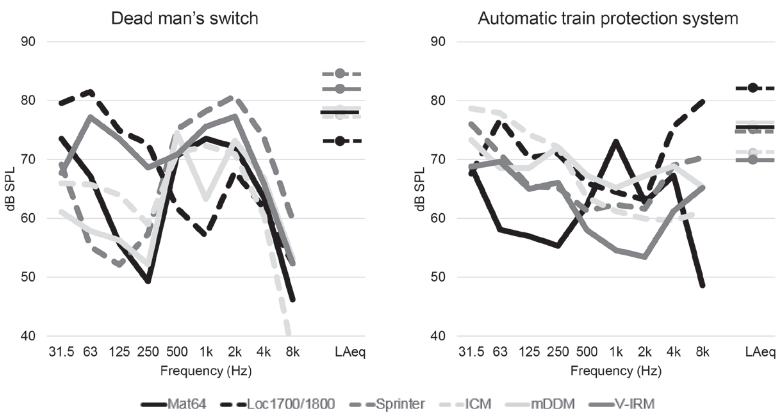

Figure 1. Octave-band spectra in dB SPL of the dead man's switch and automatic train protection system in six Dutch train types. Additionally, the A-weighted equivalent sound pressure levels are shown.

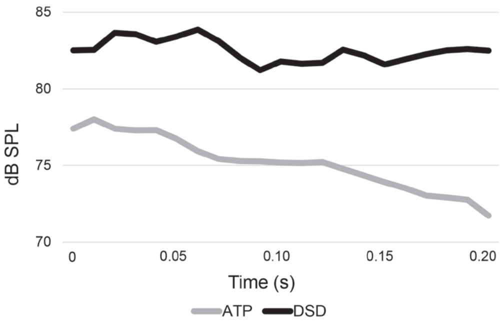

Figure 2. Decay in sound pressure level in dB SPL for the Automatic Train Protection (ATP) and The Driver's Safety Device (DSD) signal measured in Mat64. The ATP signal was filtered with a high-pass filter and a cut-off frequency of 400 Hz.

Noise-field

In total, 63 noise field measurements took place in 14 different trains with driving speed ranging from 40 to 130 km/h. The noise can be regarded as continuous noise. Figure 3 presents for each of the six train types the mean octave-band spectra and the mean L_{Aeq} of the background noise for the driving speeds 80 km/h, 100 km/h and for the maximum speed. When driving at 80 km/h, measured L_{Aeq} values range from 57.0 to 70.3 dBA. When driving at maximum speed, L_{Aeq} values range from 67.3 to 77.1 dBA. The differences in L_{Aeq} between the three driving speeds differ between the train types and this speed dependence is the largest in the ICM and the smallest in the Sprinter. No obvious changes in spectrum are observed when increasing the driving speed, except in the mDDm. When driving 100 or 130 km/h rather than 80 km/h, higher spectral noise levels were observed between 1 and 8 kHz. The results of the generalised linear model show that L_{Aeq} varies significantly between the different train types (df = 5, $F = 29.70$, $p < .001$) and driving speeds (df = 11, F = 6.80, $p < .001$). Additionally, the interaction term is significant (df = 18, $F = 2.16$, $p = .032$), which indicates that the effect of speed depends on the train type. The post-hoc tests reveal that three pairs of trains do not differ significantly from each other, specifically Loc1800 & Mat64, Mat64 & Sprinter, and ICM & V-IRM. The L_{Aeq} of Loc1800, Mat64, and the Sprinter are significantly higher than the LAeq of the ICM and the V-IRM. The L_{Aeq} of the Loc1800, is significantly higher than the L_{Aeq} of the Sprinter. Since L_{Aeq} significantly differs between the train types, we will evaluate the signal detectability of the different trains separately.

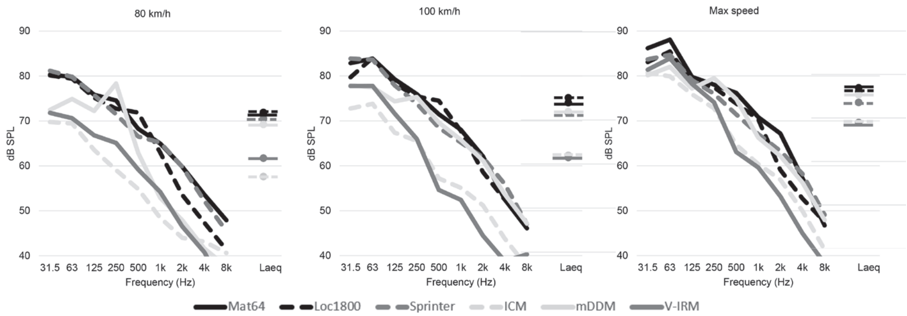

Figure 3. Octave-band spectra in dB SPL of the ambient noise field in six Dutch train types when driving at 80 km/h, 100 km/h, and when driving at maximum speed: 120 km/h for Sprinter and V-IRM and 130 km/h for the other trains. Additionally, the A-weighted equivalent sound pressure levels are shown.

Estimation of signal detectability

DSD signal

The results of the Detectsound model predictions for the DSD signal are presented in Figure 4. At least three spectral elements are observed within the design window in five of the six train types when driving at 80 km/h, in four of the six train types with a driving speed of 100 km/h, and in three of the six train types when driving at maximum speed. Spectral elements exceeding the design window are observed in four train types when driving 80 km/h, in two train types with a driving speed of 100 km/h and in one train type when driving 80 km/h. The signal peaks exceeded the design window at all driving speeds in the V-IRM. For the other train types, the outcome of the Detectsound model varied between the different driving speeds.

ATP signal

The results of the Detectsound model predictions for the ATP signal are visualised in Figure 5. At least three spectral elements are observed within the design window in two of the six train types when driving 80 km/ h, specifically the ICM and mDDm. None of the model predictions at a higher driving speed resulted in at least three spectral elements within the design window. Except from in the mDDm with a driving speed of 80 km/h, no signal peaks are observed exceeding the design window.

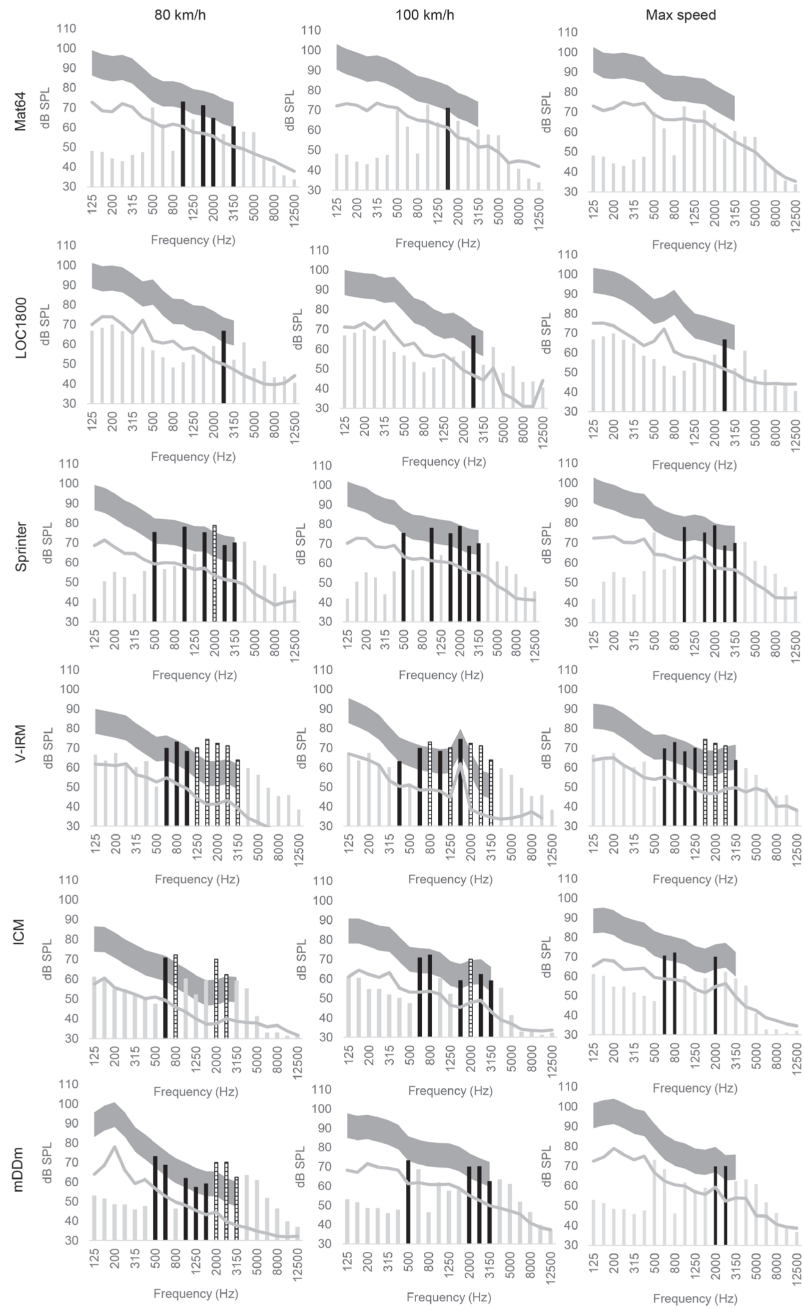

Figure 4. Output of the Detectsound software modelling the predicted detectability of the DSD signal in six Dutch train types when driving at 80 km/h, 100 km/h, and when driving at maximum speed. Spectral elements that fall within the design window are black and spectral elements that exceed the design window contain stripes.

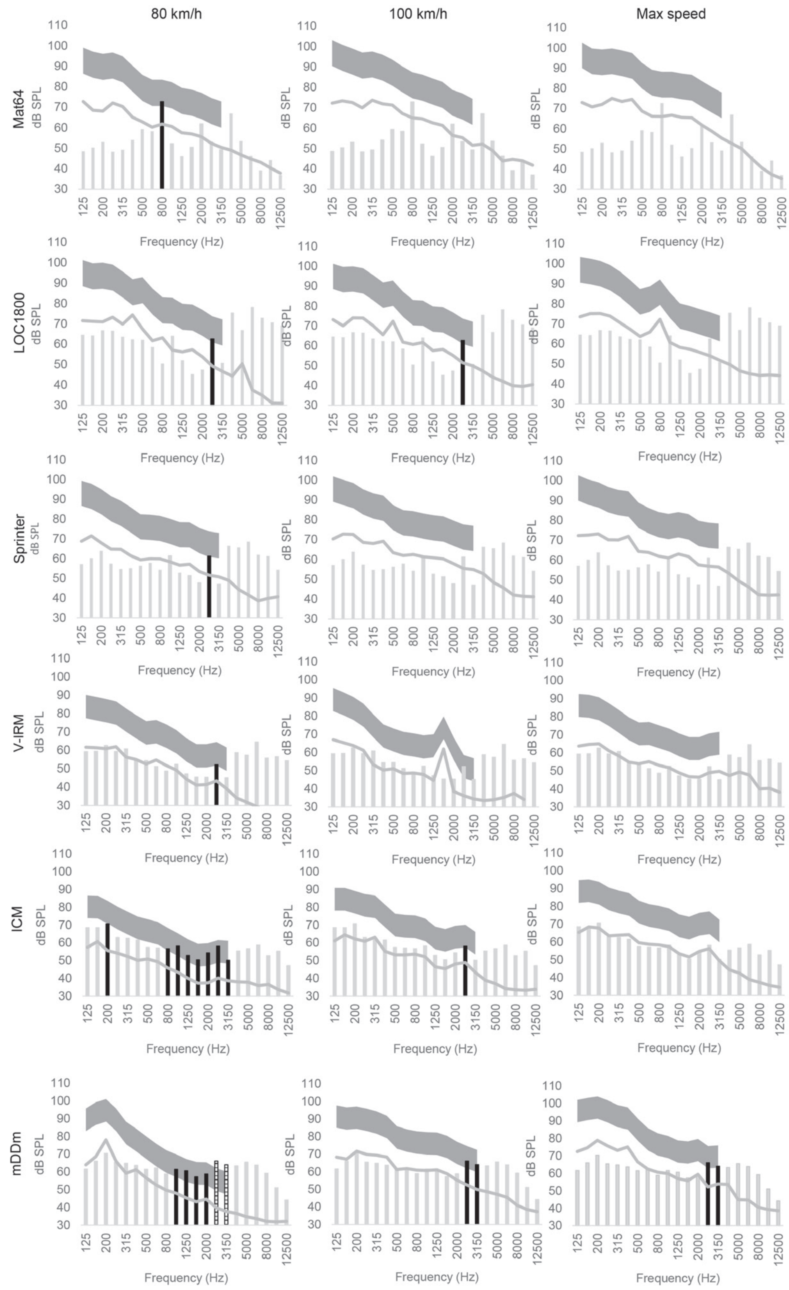

Figure 5. Output of the Detectsound software modelling the predicted detectability of the ATP signal in six Dutch train types when driving at 80 km/h, 100 km/h, and when driving at maximum speed. Spectral elements that fall within the design window are black and spectral elements that exceed the design window contain stripes.

Signal detectability in a laboratory setting

All subjects completed the experiment. There was no missing data. The A-weighted SNR_{50} for the DSD and ATP signal in the background noises of the six train types are expressed in dB SNR in Table 1. For detecting the DSD signal, the SNR_{50} ranged from -32.8 to -23.4 dB SNR. For detecting the ATP signal, the SNR_{50} ranged from -47.4 to -25.0 dB SNR. Except for one train type, the SNR_{50} was lower for detecting the ATP signal compared to the DSD signal.

Table 1. Mean A-weighted signal-to-noise ratio's at which fifty percent of the warning signals were detected correctly by six normally-hearing individuals

	DSD signal SNR_{50} (SD)	ATP signal SNR_{50} (SD)
Mat'64	-23.4 (3.0)	-44.2 (3.6)
Loc1800	-27.7 (1.3)	-39.5 (3.0)
Sprinter	-28.1 (4.8)	-47.4 (4.4)
ICM	-29.2 (2.2)	-44.6 (3.2)
mDDm	-32.8 (1.7)	-25.0 (1.3)
V-IRM	-26.6 (1.6)	-44.8 (3.4)

ATP indicates automatic train protection; DSD, Dead Man's Switch; SNR_{50}, the signal-to-noise ratio at which 50 percent of the warning signals was detected correctly.

Discussion

This study examined the acoustic characteristics of the warning signals and the ambient noise in Dutch train cabins to evaluate the effectiveness of these warning signals when presented to normally- hearing locomotive engineers. The DSD and ATP signal were shown to have different acoustic characteristics and the ambient noise levels depended on train type and driving speed. Although the DSD and ATP signals both contained more sound energy than the background noise, the model predictions indicated that the detectability of the signals was critical in a number of conditions.

The levels of the warning signals were – in accordance with the advice in ISO 7731 – larger than 65 dBA and softer than 118 dBA. A spectral analysis indicated that the measured DSD signals did adhere to the ISO requirements, but the ATP signals did not, because most sound energy was measured above 4000 Hz. The measured intensity of the background noise varied from 53.2 to 77.1 dBA. This is roughly in line with an earlier study that reported maximum noise exposure levels between 70 and 80 dBA for locomotive engineers in Norway (Lie et al., 2013). Higher maximum noise levels were measured in Chinese trains, varying from 88 to 93 dBA (Peng et al., 2019). The significant effect of train type and driving speed on the noise level confirmed the results of Kurze et al. (2000) and (Pronello, 2003).

According to ISO 7731, warning signals will be clearly detectable for normally-hearing employees if the signal energy in one or more 1/3 octave bands is more than 13 dB higher than the effective-masked-threshold (ISO, 2003). The Detectsound analysis showed that this criterion is fulfilled for the DSD signal in all trains, except for the Mat64 when driving at maximum speed. For the ATP, this criterion is not fulfilled in most trains when driving at maximum speed. The ISO method only takes into account the highest signal component and ignores other spectral components. Using the Detectsound criterion of having at least three signal peaks within the design window for detection, we anticipated on the fact that detection of tonal signals may be better when multiple spectral peaks are more than 13 dB higher than the effective-masked- threshold (Edworthy, 1994).

The lack of spectral elements within the design window does not necessarily mean that the signal is inaudible, which is shown by the results of the laboratory measurements. The SNR_{50} varied from -47.4 to -23.4 dB SNR, indicating that the warning signals remain audible when adjusted at levels significantly below the level of the background noise. Contrary to the Detectsound analysis, the outcomes of the laboratory measurements were more favourable for the ATP signal than for the DSD signal in most trains. A reason might be that we averaged the ATP measurements over the first 200 ms, although the sound level of the ATP signal decays over time. The higher onset of the ATP signal might result in better signal detectability than the analysis of the short-time averaged level suggests. Another explanation is that Detectsound may underestimate signal detectability when signal peaks are present at higher frequencies. According to ISO 7731, it is advised to include warning signals with signal components in the range of 500 to 2500 Hz when designing a warning signal (ISO, 2003). In line with this recommendation, the Detectsound model does not take spectral elements above 3100 Hz into account, anticipating on employees with high-frequency hearing loss due to presbycusis and/or noise exposure (Giguère et al., 2008). For the DSD signal, the prominent signal peaks were present between 500 and 4000 Hz and thus fall mostly within the spectrum of the design window. Contrary, the most prominent peaks of the ATP signal were present between 4000 and 8000 Hz.

In this study, we focussed on the spectral elements of the warning signals, although the temporal structure of a warning signal can influence detectability (Misdariis et al., 2013). We observed distinctive differences in temporal characteristics between the two warning signals. The ATP signal decays over time and the DSD signal does not, which might facilitate discrimination between the two signals (Edworthy, 1994; Graham, 1999). Moreover, the ATP signal is presented once if a change in speed is required and three times when the change in speed is accomplished. If the maximum speed is exceeded, the ATP is presented with a longer duration of approximately three seconds. The ATP signal might be easier to detect if it is presented three times or with a longer duration. However, a detailed analysis of the temporal structure of the warning signals was beyond the scope of this study.

Some study limitations need to be mentioned. First, the criteria from the Detectsound model and the ISO are based on warning signals that can occur unexpectedly. In a train cabin, the auditory signals occur often and are thus expected and very well-known by the driver. However, because it is vital that a locomotive engineer does not miss these warning signals, even in very tense situations, the detection models used are deemed relevant. Second, since the acoustical measurements took place in 2006 and 2007, the measurements in this study do not cover all train types that are currently in use. Also, all Mat64s have been decommissioned in 2016. The result that the detectability of the DSD and ATP signal was critical in the Mat64 is therefore less relevant for current practice. The train equipment of the included trains has not changed, with the exception that it used to be possible to open the window in some locomotive cabins, but at present these windows cannot be opened anymore. This does not influence the applicability of our results, since all measurements were performed with closed windows. Third, the experimental design did not allow full control over the selection of the railway tracks. Consequently, the number of measurements and the measured driving speed differed between the train types. Fourth, it is not possible to use these measurements to obtain an accurate estimate of the daily noise exposure of locomotive engineers. However, since the average measured sound levels were much lower than 80 dBA, it is reasonable to assume that prolonged driving on these trains does not exceed the current Dutch and European first action level of 80 dBA averaged over an eight-hour shift (STB10053, 2006; Directive 2003/10/EC).

The large differences in predicted signal detectability between different driving situations suggest that it is important to take different driving situations into account when evaluating signal detectability inside a train cabin. Having high enough signal levels to ensure good signal detectability at maximum speed can imply that signals are too loud at lower speed rates. Warning signals that automatically adjust their level according to the background noise may therefore be warranted. Also, it is important to not only focus on detectability, but also evaluate the subjective experience of locomotive engineers. A signal with good audibility at high driving speed, may be experienced as annoying at a lower speed. Although it is likely that the results of this study reflect the real-life working situation of Dutch locomotive engineers, situations may occur in daily practice that make signal detection even harder. For example higher noise levels have been associated with passing vehicles at station platforms (Neitzel et al., 2009) and with crossing a tunnel (Dinno et al., 2011; Phan & Jones, 2017). Since the underlying physical mechanism for detecting an alarm in noise might depend on the SNR (Karunarathne et al., 2018), we need to be careful with generalizing the results to other SNR's.

Contrary to an earlier study that assessed the acoustic requirements for speech communication in Dutch train cabins (Houben et al., 2007), we found that the acoustic requirements for warning signal detectability were not always met. Thus, the fact that a workplace fulfils the acoustic conditions for speech communication, does not necessarily mean that the conditions for another hearing-critical task, detecting warning signals, are also fulfilled. This stresses the importance of evaluating the acoustical requirements for different hearing-critical jobs separately. By assessing the acoustical requirements in multiple work-settings, the work settings can be identified in which performance of the hearing-critical job is the most critical. This has the advantage that acoustical or environmental work modifications can then be undertaken to ensure safe and effective job performance in all work settings. Further, identification of the most hearing-critical work situations is useful for designing auditory fitness for job assessments. If an employee is capable of fulfilling an auditory task sufficiently in the most unfavourable acoustic environment, it is likely that the same task will also be successfully fulfilled in a less noisy environment. This method could be used to assess multiple workplaces in which hearing-critical jobs are performed, such as the workplace of police officers, firefighters, and coast guard employees.

This research revealed that the noise levels in Dutch train cabins range between 53.2 and 77.1 dBA, depending on the train type and driving speed. Although the levels of the auditory warning signals are higher than the background noise levels, the acoustical requirements for signal detectability were not met in multiple driving conditions, especially at higher speed. Normally-hearing subjects who can make use of high frequency signal peaks were able to compensate for the suboptimal acoustic conditions, but difficulties can be expected in unfavourable driving situations or when the engineer suffers from hearing loss. To ensure safe and effective job performance in all driving situations, the detectability of warning signals in Dutch train cabins warrants further attention, particularly when hearing loss is present. Acoustical, environmental or work modifications might be required to prevent situations with insufficient audibility in hearing-impaired engineers.

Chapter 6

Measuring auditory fitness in locomotive engineers: development and validation of a signal detection test

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Abstract

Purpose

To perform their job safely and effectively, locomotive engineers are required to detect auditory warning signals in the noisy work setting of a train cabin. Based on audio recordings of Dutch train cabins, we have developed a task and job-specific test for assessing the engineer's ability to detect the two acoustic warning signals for the Dutch situation. The aim of this study was to evaluate the reliability, agreement, and construct validity of this test.

Design

Two experiments were performed. In the first experiment, reliability and agreement of the signal detection test were assessed. Normally-hearing individuals (N = 12) completed a signal detection test twice in twelve driving conditions. In the second experiment, construct validity was assessed. We retrospectively identified locomotive engineers, suspected of being hearing impaired, who were referred to the Amsterdam UMC for an auditory fitness for job assessment. All included engineers (N = 83) performed the signal detection test in four driving conditions, underwent pure-tone audiometry and two speech perception tests in noise, and rated the effort and concentration it takes to detect the auditory signals. Seven a priori formulated hypotheses were tested.

Results

In the first experiment, sufficient reliability and agreement were found in nine driving conditions (ICC = 0.54–0.81; standard error of measurement = 1.15 – 1.92 dBA), poor reliability in two driving conditions (ICC < 0.50), and poor agreement in one driving condition (standard error of measurement = 2.67 dBA). In the second experiment, the results of the signal detection test correlated moderately with the pure-tone thresholds, speech reception threshold in fluctuating noise, and engineer's subjective rating of effort and concentration, but not with the speech reception threshold in continuous noise. According to the hypotheses, poorer test scores were obtained by hearing aid users compared with non-hearing aid users.

Conclusion

The signal detection test has sufficient reliability and agreement in all but three driving conditions. This study provides evidence supporting the construct validity of the signal detection test in locomotive engineers. The moderate associations with conventional hearing tests show that the conventional hearing tests did not cover the whole construct measured with the signal detection test. The results, therefore, underpin the importance of evaluating the ability to detect auditory warning signals separately from other hearing-critical job tasks.

Introduction

Locomotive engineers perform a hearing-critical job—just like police officers, firefighters, and many other employees—since they are required to perform auditory tasks that depend on sufficient hearing acuity (Zoer et al., 2014). First, speech communication is required when communicating to the signaller, conductor, and others by answering calls, making announcements, and using communication equipment. Second, the detection of auditory warning signals is needed in case of events that can compromise safety (Zheng et al., 2007). The noisy work environment of a train cabin makes it particularly challenging to perform these auditory tasks, especially when hearing loss is present (Giguère et al., 2008). If an engineer lacks sufficient auditory sensitivity and discriminative power, this may decrease the operational effectiveness. Moreover, it may constitute a safety risk for this engineer, the fellow workers, and the public.

If the inability to perform a hearing-critical task can cause inefficiency or safety risks, auditory fitness for job assessments can be performed (Laroche et al., 2008). These hearing assessments must determine if an employee is able to perform the various auditory tasks needed in the job (Tufts et al., 2009). Frequently, auditory fitness for job assessments lack sufficient diagnostic tools to be task and job specific (Tufts et al., 2009). Pure-tone audiometry is often used, although it has been shown to be a poor predictor of functional hearing abilities (Moore, 2007; Tufts et al., 2009). Experience, skill on the job, or the job protocol may allow employees to compensate for the hearing loss (Middelweerd et al., 1990; Soli, 2003). Also, the relationship between pure-tone audiometry in quiet and signal detection in noise might differ between different signals, depending on the frequencies at which the most prominent signal peaks can be heard (Van der Hoek-Snieders et al., 2021).

A number of researchers have therefore developed and validated tests and models to assess the functional ability of speech communication in different workplaces (Goldberg, 2001; Laroche et al., 2008; Laroche et al., 2005; Laroche et al., 2003; Le Prell & Clavier, 2017; Soli, Giguère, et al., 2018). Using conventional hearing-in-noise tests, predictive models have been developed to predict speech communication in real-world noises, for example, in the workplace noise of police constables (Laroche et al., 2003). This has resulted in the general recommendation that speech testing in noise should be performed when assessing functional speech communication (Tufts et al., 2009). Despite the increased effort that has been invested to develop valid tests and models to assess the functional ability of speech communication, there is only limited evidence on how to assess an employees' ability to detect acoustic warning signals.

A computational model has been developed to predict the detectability of warning signals in noise based on the acoustic characteristics of the signal and the noise, as well as the hearing status of an individual or a group (Zheng et al., 2003). However, there is limited evidence for the validity of this model, and the model tends to underestimate warning signal detectability (Van der Hoek-Snieders et al., 2021). This might be due to the fact that this model has been developed to specify the optimal acoustic characteristics of warning signals rather than for assessing if an individual is capable of performing the job-specific, hearing-critical tasks. Since a valid model for assessing signal detectability is lacking and pure-tone audiometry has been shown to be a poor predictor of signal detection in noisy environments, it has been proposed to use real-world simulation tests instead (Tufts et al., 2009).

A simulation test can be developed with audio recordings of a specific workplace. We have developed a signal detection test based on audio recordings of Dutch locomotive cabins. Before this signal detection test can be implemented as part of the auditory fitness for job assessment of locomotive engineers, the clinimetric properties of the test should be determined (De Vet et al., 2003). Reliability is important when a test is used to discriminate between individuals because reliability is defined as the ability of a test to differentiate among subjects despite measurement error. For evaluative instruments, agreement parameters are also required. Agreement reflects the degree to which scores or ratings are identical when assessed in repeated measurements (Kottner et al., 2011).

In addition, it is important to know whether a test measures what it intends to measure. Therefore, the validity should be determined. The construct 'the ability to detect acoustic warning signals in the acoustic environment of a train cabin' is examined with the signal detection test. To examine the construct validity of the test, it should be compared with a gold standard. However, as no gold standard is present at this moment, construct validity can be assessed by testing hypotheses about the relations between the signal detection test and related constructs (De Vet et al., 2011). Since the clinimetric properties of the signal detection test are not yet determined, we aimed to evaluate the reliability, agreement, and construct validity in a population of Dutch locomotive engineers.

Materials and methods

Signal detection test

The purpose of the signal detection test is to assess auditory fitness for job. The test was developed based on the acoustic characteristics of the real-working environment of Dutch locomotive engineers, where two auditory warning signals need to be reliably detected. Therefore, audio recordings were made in trains under different conditions (e.g., at different speeds), for details, see Van der Hoek-Snieders et al. (2021). These audio recordings were made during normal operation of the trains and reproduced in a test situation. Prior, during, and after the acoustical measurements, the recording system was calibrated and checked. To determine the correct level of the recordings during off-line analysis, a calibration tone was recorded. When these audio recordings were made, six electric train types were in use for passenger conveyance. All were included for the acoustic measurements. The two auditory warning signals present in these train cabins were also both included.

- The signals to be detected were the two warning signals for each specific train type: The Driver Safety Device (DSD) signal is a buzzer type signal that contains its most prominent signal peaks at 2000 and 4000 Hz. The Automatic Train Protection (ATP) signal sounds bell-like and contains its most prominent signal peaks at 4000 and 8000 Hz.

- The interfering noise was a recording of the ambient noise of the respective train type driving at maximum speed. The noise inside a train cabin can be produced by the wheels, the track, the friction between both, and the train's equipment, such as the motor, compressor, and air conditioning (Atmaja et al., 2018). The noise can be regarded as continuous.

The level and spectrum of the noise, as well as the acoustic characteristics of the warning signals, differ between the six train types. In Figure 1, the acoustic environment of two train types is shown when driving at maximum speed, including the level and spectrum of the ambient noise and two acoustic warning signals.

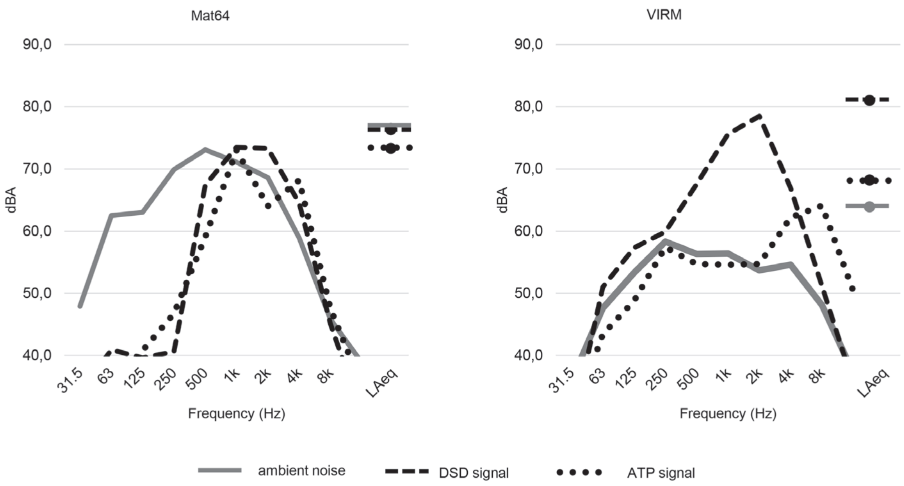

Figure 1. Octave-band spectra in dBA of the ambient noise and auditory warning signals (DSD and ATP signal) present in two Dutch train types (Mat64 and V-IRM). In addition, the A-weighted equivalent sound pressure levels are shown. ATP indicates automatic train protection; DSD, dead man's switch; LAeq, the A-weighted sound pressure level.

Every combination of a train type with a warning signal (DSD or ATP signal) is called a driving condition. The combination of two warning signals and noise environments of each of the six train cabins resulted in twelve possible driving conditions.

The signal detection test uses a stepwise two-alternative forced-choice adaptive approach to determine the detection threshold, defined as the lowest signal-to-noise ratio (SNR) at which 50 percent of the warning signals can be heard. This test outcome will be referred to as SNR_{50}. The noise level was fixed at a presentation level corresponding to the real-world noise level at the train's maximum speed. The signal level varied and started at a signal level of 30 dBA higher than required to achieve the expected SNR_{50}. After each correct response, the signal level decreased with a step size of 4 dB until the participant failed to detect the signal correctly. Then the signal level increased again and followed a one-up one-down procedure with a 2 dB step size. The test was continued until five reversals were obtained. It took approximately a minute to complete one driving condition and twelve minutes to complete the full test for all twelve driving conditions. The test was programmed in MATLAB (MathWorks, 2005).

Test procedure

The detection test was performed in a sound-isolated booth in a free-field setting. The participant was sitting in a chair in the middle of the booth and was surrounded by six speakers located at azimuths of 0°, 45°, 80°, 180°, 280°, and 315°, and a subwoofer. The distance between the chair and the speakers varied from 55 to 140 cm. We used uncorrelated noise signals, and the speaker-system was calibrated such that the sound at the location of the participant (without the participant in place) matched the sound spectrum that was recorded in the train. All subjects were instructed to push a button when a signal was heard, even if the signal was very soft. To get familiar with the test procedure, the test started with a practice round using one signal in one driving condition. Afterwards, the detectability of the DSD and ATP signals was assessed for the different driving conditions.

Experiment 1

The purpose of experiment 1 was to obtain reference values for the signal detection test and to examine the test-retest reliability and measurement error of the test.

Participants

Twelve normally-hearing adults were recruited between November and December 2019. Only subjects with pure-tone thresholds of 20 dB HL or better at the octave frequencies between 250 and 8000 Hz, at both ears, were included. All subjects provided written informed consent. The Ethics Committee of the Academic Medical Center declared that no formal approval of the detailed protocol was required according to the Dutch Medical Research Involving Human Subjects Act (No. Xt4-148).

Thirteen subjects were recruited through an online advertisement to participate in the study. One subject was excluded because the criterion of hearing thresholds at or below 20 dB HL was not met. This resulted in a study population of twelve normally-hearing subjects, including seven females and five males with a mean age of 29.5 (range 25–36).

Procedure

After completing pure-tone audiometric screening, the signal detection test was applied. The detectability of the DSD and ATP signal were both assessed in the ambient noise of six different train types. For this experiment, the signal detection test was conducted twice in all driving conditions, with a 15-minute break separating the two sessions. The order of the driving conditions was counterbalanced using Latin squares (Wagenaar, 1969). The first author was the test leader for all subjects.

Statistical analysis

The Intraclass Correlation Coefficient (ICC) was used to assess reliability since this measure assesses the strength of the correlation while taking into account possible systematic differences (Koo & Li, 2016). When comparing the size of this correlation coefficient to Pearson coefficients, one should take into account that generally, the ICC coefficients are smaller than Pearson coefficients. ICCs were calculated for all driving conditions to assess the test-retest reliability using an ICC 2-way mixed-effects model with an absolute agreement definition (De Vet et al., 2006). The interpretation was as follows: below 0.50, poor; between 0.50 and 0.75, fair; between 0.70 and 0.90 good; above 0.90, excellent (Perinetti, 2018).

Further, we calculated the mean difference between the test and the retest measurements and the SD of this difference. We calculated the standard error of measurement (SEM) using the formula SD * √(1-R), with R equal to ICC and SD equal to √(total variance). The smallest detectable change (SDC) was calculated as an indication of measurement error using the formula 1.96 * √2 * SEM.

Data organization and the statistical analysis were performed using the Statistical Package for Social Sciences version 25.0 (Armonk New York USA).

Experiment 2

The purpose of experiment 2 was to assess the construct validity of the signal detection test. Therefore, we identified locomotive engineers who performed their auditory fitness for job assessment at the Amsterdam UMC. They underwent a job assessment because they were suspected of being hearing impaired. These engineers performed the signal detection test in four driving conditions in addition to the conventional hearing tests that are required to pass the auditory fitness for job assessment.

Participants

At the Amsterdam UMC, the signal detection test is routinely performed as part of the auditory fitness for job assessment. A retrospective data collection was therefore used to assess the construct validity. We retrospectively identified locomotive engineers who were referred to the Amsterdam UMC for an auditory fitness for job assessment. Eligible engineers were aged between 18 and 67, and underwent pure-tone audiometry, a speech reception test in noise, and the signal detection test. All engineers received a letter with information about the study. Because of the retrospective study design, an opt-out procedure was applied. The ethics committee at the Amsterdam UMC declared that no formal approval of the detailed protocol was needed according to the Dutch Medical Research Involving Human Subjects Act (No. 18_369 no. 18.421).

A prospective power calculation was performed to determine the sample size required for the hypotheses testing. To determine the sample size required for detecting correlations of at least 0.3 with an Alpha error of 5%, a prospective power calculation was performed with G*Power software version 3.1 (Faul et al., 2007). To obtain a power of 80%, the inclusion of 67 locomotive engineers would be necessary.

A total of 91 locomotive engineers fulfilled the inclusion criteria, of which eight objected to participate in the study. In total, 83 locomotive engineers were included, 81 males and two females with a mean age of 56 years (range, 33–66). Their mean number of working hours was 35 (SD, 4.1). The participants that owned hearing aids (about 20%) did not use them during the signal detection test and the speech-in-noise test.

Procedure

Conventional hearing tests

Pure-tone audiometry (ISO 8253-1 1989) was performed in a sound-isolated booth using calibrated Interacoustics Clinical Audiometers (model AC-40) and Decos audioNigma with TDH 39p headphones. Air conduction and bone conduction thresholds (with appropriate masking if necessary) were reported in dB hearing level (dB HL) at octave frequencies from 250 Hz to 8000 Hz. For each frequency, we calculated the binaural hearing impairment (BHI) by combining the thresholds of the left and right ear, with a five to one weighting favouring the better ear (American

Academy of Otolaryngology, 1979). We also calculated an overall BHI combining the mean pure-tone thresholds at 2000 and 4000 Hz (the frequencies at which the DSD signal has its most prominent signal peaks) and an overall BHI combining the mean pure thresholds at 4000 and 8000 Hz (the frequencies at which the ATP signal has its most prominent signal peaks).

Speech reception in noise was assessed in an unaided, free field setting (S0N0) using everyday Dutch sentences. The noise level was fixed at 65 dBA in most cases and at 70 dBA or 75 dBA in case of severe hearing loss. Two different tests were used: the one developed by Plomp and Mimpen (1979) or the test developed by Versfeld et al. (2000). These sentence materials have been shown to result in similar test outcomes (Versfeld et al., 2000). The speech reception test was performed in continuous and single-speaker fluctuating noise. We calculated the speech reception threshold (SRT) for the two noise conditions separately.

Subjective rating of effort and concentration

All engineers were asked on a five-point Likert scale: Does detecting auditory warning signals cost you effort and concentration at your workplace? The answer options were as follows: no, a small amount, a moderate amount, and a lot.

Signal detection test

After completing the practice tests from experiment 1, the signal detection test was applied. Due to time constraints, not all 12 driving conditions could be assessed. Instead, the SNR_{50} was determined in four different driving conditions. Detection of DSD and ATP signal was assessed in the Mat64, the train with the highest ambient noise level, and in the V-IRM, the train type that is relevant for most Dutch engineers.

Construct validity

Construct validity was assessed by the degree to which the SNR_{50}'s of the signal detection test were consistent with predefined hypotheses. We tested seven hypotheses (Table 3), of which four concerned the association between the signal detection test and conventional hearing tests. We expected moderate, positive correlations between the SNR_{50} and the pure-tone audiometry thresholds at the frequencies at which the warning signal is the most prominent (hypothesis

1 and 2). We expected moderate, positive correlations between the SNR_{50}, and the SRT of a speech reception test performed in continuous noise (hypothesis 3) and in fluctuating noise (hypothesis 4). In addition, we expected moderate, positive correlations between the SNR_{50} and the engineers' subjective rating of concentration and effort it takes to detect auditory warning signals in the train cabin (hypothesis 5). A moderate correlation was expected rather than a strong correlation, since the subjective rating was provided for the purposes of an auditory fitness for job assessment. We hypothesized only a moderate correlation (and not a strong correlation), since there is a great risk of reporting bias. Locomotive engineers may under-report their subjective difficulties with detecting the auditory warning signals if they are afraid of not passing the fitness for job assessment (with the worst-case scenario of losing their job). Further, we expected to find a higher (poorer) mean SNR_{50} in the ambient noise of the Mat64 compared with V-IRM (hypothesis 6), since the analysis of Van der Hoek-Snieders et al. (2021) showed a less favourable acoustic environment in the Mat64. Finally, we expected significantly higher (poorer) SNR_{50}'s on the signal detection test in locomotive engineers wearing hearing aids, compared with engineers who do not wear hearing aids (hypothesis 7). Locomotive engineers who have decided to wear hearing aids are expected to experience more severe functional listening difficulties compared with engineers who do not wear hearing aids.

Statistical analysis

The a priori formulated hypotheses regarding the expected correlation between the signal detection test, and the conventional hearing tests were tested by calculating Pearson correlation coefficients. The assumptions with respect to normality and linearity were checked. Biserial correlation coefficients were calculated between the SNRs derived with the signal detection test and the subjective rating of effort and concentration it takes to detect auditory warning signals (Kraemer, 2014). Therefore, this subjective rating was dichotomized. The first category was reserved for engineers who answered that detecting auditory warning signals did either not take effort and concentration, and the second category for engineers who answered that detecting auditory warning signals did take extra effort and concentration to some extent. The hypotheses regarding group differences were tested by t-tests with a p cut-off value of 0.05, specifically a paired t-test for testing hypothesis 6 and an independent t-test for testing hypothesis 7. Data organization and the statistical analysis were performed using the Statistical Package for Social Sciences version 25.0 (Armonk New York USA).

Results

Experiment 1

The experiment was completed by all included subjects, and there was no missing data. A normal distribution was confirmed for all SNR_{50} values. The range varied from 6.9 to 16.5 dbA per driving condition.

For the DSD signals, the mean SNR_{50} varied between –30.2 and –23.4 dBA with ICCs between 0.16 and 0.67 (Table 1). SEMs ranged from 1.2 to 2.0 dBA, corresponding to SDCs between 3.2 and 5.6. For the ATP signal, the mean SNR_{50} varied widely between –47.3 and –23.6 dBA with ICCs between 0.53 and 0.81. SEMs ranged from 1.3 to 2.7 dBA, corresponding to SDCs between 3.6 and 7.4 dBA. No systematic differences were observed between the first and the second assessment of the signal detection tests.

Table 1. Reproducibility of measurement of the signal-detection test for the DSD and ATP signal in the ambient noise of six different train types

	Mean ± SD in dBA	ICC	$Mean_{diff}$	SD_{diff}	LoA low ; up	SEM	SDC
DSD signal							
Mat'64	-23.4 ± 2.1	.66	0.2	1.8	-3.3 ; 3.7	1.3	3.5
Loc1800	-26.1 ± 2.3	.29	-0.6	2.8	-6.1 ; 4.8	2.0	5.5
Sprinter	-24.6 ± 2.0	.54	0.6	1.9	-3.1 ; 4.3	1.4	3.7
ICM	-27.8 ± 2.2	.16	-0.9	2.9	-6.5 ; 4,8	2.0	5.6
mDDm	-30.2 ± 2.3	.62	0.4	2.1	-3.6 ; 4.4	1.5	4.0
V-IRM	-26.8 ± 2.0	.67	0.4	1.6	-2.8 ; 3.6	1.2	3.2
ATP signal							
Mat'64	-47.0 ± 3.8	.75	0.8	2.7	-4.5 ; 6.1	1.9	5.3
Loc1800	-39.9 ± 2.5	.73	0.1	1.9	-3.7 ; 3.8	1.4	3.7
Sprinter	-47.3 ± 2.8	.81	0.1	1.8	-3.4 ; 3.7	1.3	3.6
ICM	-45.5 ± 3.4	.55	-0.3	3.8	-7.7 ; 7.1	2.7	7.4
mDDm	-23.6 ± 2.9	.73	-0.6	2.2	-4.9 ; 3.7	1.6	4.3
V-IRM	-44.5 ± 2.2	.53	-0.5	2.6	-5.5 ; 4.5	1.8	5.0

DSD indicates Dead Man's Switch; ATP, Automatic Train Protection; Mean, pooled mean of the two assessments; Meandiff , mean difference between the two assessments; SDdiff, standard deviation of the mean difference; LoA, limits of agreement, SEM, standard error of measurement; SDC, smallest detectable change.

Experiment 2

A normal distribution was confirmed for all BHI, SRT, and SNR_{50} values. The assumption of linearity was fulfilled.

Table 2 shows the hearing status of the included participants, measured during their auditory fitness for job assessment. The majority of the engineers (65%) reported that detecting auditory warning signals at their workplace does not take extra effort or concentration. The other engineers reported that detecting auditory warning signals takes extra effort or concentration to some extent, specifically to a small amount (29%) or to a moderate amount (6%).

Table 2. Hearing status of the included locomotive engineers that performed an auditory fitness for job assessment (*N* = 83)

	Value (SD)	**Min ; Max**
Pure-tone audiometry		
BHI 250 Hz	9.9 (9.24) dB HL	-5.0 ; 61.7 dB HL
BHI 500 Hz	13.4 (9.30) dB HL	0.0 – 57.5 dB HL
BHI 1000 Hz	19.8 (10.59) dB HL	-3.0 ; 53.3 dB HL
BHI 2000 Hz	30.6 (11.15) dB HL	8.0 ; 70.0 dB HL
BHI 4000 Hz	51.0 (12.53) dB HL	23.0 ; 78.0 dB HL
BHI 8000 Hz	58.6 (20.63) dB HL	12.0 ; 105.8 dB HL
BHI mean 2000 & 4000 Hz	40.3 (9.40) dB HL	20.0 ; 70.0 dB HL
BHI mean 4000 & 8000 Hz	54.2 (14.93) dB HL	22.5 ; 85.0 dB HL
Speech reception test in noise		
SRT in continuous noise	-3.7 (1.7) dB SNR	-8.2 ; 1.2 dB SNR
SRT in fluctuating noise	-7.6 (3.1) dB SNR	-13.8 ; 1.4 dB SNR
Signal detection test DSD signal		
Mat'64	-17.5 (4.46) dBA	-29.2 ; -5.2 dBA
V-IRM	-23.7 (4.01) dBA	-29.8 ; -9.8 dBA
Signal detection test ATP signal		
Mat'64	-24.4 (8.3) dBA	-46.9 ; -7.9 dBA
V-IRM	-30.9 (5.9) dBA	-41.1 ; -15.9 dBA

ATP indicates Automatic Train Protection; BHI, Binaural Hearing Impairment; DSD, Dead Man's Switch; SNR, signal-to-noise ratio; SRT, Speech Reception Threshold.

The results of the hypotheses testing are shown in Table 3. The associations between the SNR_{50} and the pure-tone thresholds at which the warning signal is the most prominent were moderate to strong (hypothesis 1 and 2). The correlation between the SNR_{50} and the speech reception in noise test was weak in continuous noise (hypothesis 3) but moderate in fluctuating noise (hypothesis 4). Moderate associations were observed between the SNR_{50} and the subjective rating of locomotive engineers of the effort and concentration it takes to detect auditory warning signals (hypothesis 5). The mean SNR_{50} was significantly higher (poorer) when the test was performed in the Mat64 compared with the V-IRM (hypothesis 6). The mean SNR_{50} was significantly higher in hearing aid users compared with non-hearing aid users (hypothesis 7). Therefore, six of the seven hypotheses were confirmed by the results in the test population.

Table 3. The construct validity (hypotheses testing) of the signal detection test

Hypothesis	**Confirmed**	**DSD signal**		**ATP signal**	
	Yes/no	**Mat64**	**VIRM**	**Mat64**	**VIRM**
1. The SNR_{50} derived with the DSD-signal detection test was expected to show a moderate, positive correlation with the BHI of the pure-tone thresholds at 2000 and 4000 Hz.	Yes	$r=.410$	$r=.523$	-	-
2. The SNR_{50} derived with the ATP-signal detection test was expected to show a moderate, positive correlation with the BHI of the pure-tone thresholds at 4000 and 8000 Hz.	Yes	-	-	$r=.744$	$r=.547$
3. The SNR_{50} derived with the signal detection test was expected to show a moderate, positive correlation with the SNR derived with a speech-in-noise test performed in continuous noise.	No	$r=.143$	$r=.281$	$r=.279$	$r=.312$
4. The SNR_{50} derived with the signal detection test was expected to show a moderate, positive correlation with the SNR derived with a speech-in-noise test performed in fluctuating noise.	Yes	$r=.343$	$r=.307$	$r=.337$	$r=.338$
5. The SNR_{50} derived with the signal detection test was expected to show a moderate, positive correlation with locomotive engineer's subjective rating of the effort and concentration it takes to detect auditory warning signals at their workplace	Yes	$r=.358$	$r=.461$	$r=.364$	$r=.429$
6. The mean SNR_{50} was expected to be significantly higher when performed in the ambient noise of the Mat64 than when performed in the ambient noise of the VIRM.	Yes	$p<.001$		$p<.001$	
7. Locomotive engineers who wear hearing aids were expected to score significantly poorer on the signal detection test than locomotive engineers who do not wear hearing aids	Yes	$p<.001$	$p<.001$	$p=.010$	$p=.010$

SNR_{50} indicates Signal-to-Noise Ratio at which 50 percent of the warning signals can be heard, Low, correlation < 0.30; moderate, correlation 0.30-0.70; high, correlation > 0.70.

Discussion

This study evaluated the reliability, agreement, and construct validity of the signal detection test in a population of Dutch locomotive engineers.

Experiment 1

The results of the test-retest experiment indicated sufficient reliability and agreement in most driving conditions. The ICCs were fair to good in all, but two driving conditions. Poor ICCs were found in the driving conditions of the ICM (both DSD and ATP signal) and Loc1800 noise (DSD only). This might be explained by the relatively small sample size of experiment 1. In a smaller sample, the impact of deviating values can be higher. Due to the relatively small range in SNR_{50} that was measured in experiment 1, we conclude that the reliability of the signal detection test is only moderate when used in normally-hearing subjects. When taking into account that the range in SNR_{50} as measured in experiment 2 was much larger, we expect the reliability of the signal detection test to be higher when used in hearing-impaired locomotive engineers. This should be confirmed by future research. Based on Bujang & Baharum (2017), we recommend a sample size of at least 22 for detecting ICC values of 0.5 and higher. Since poor ICCs and substantially higher SEMs were found in the driving conditions of the ICM (both DSD and ATP signal) and Loc1800 noise (DSD only), we recommend not to use the test for research or clinical purposes in these three driving conditions.

In the ambient noise of all but one train cabin, the ICC was higher for the ATP signal than for the DSD signal. This might be related to the fact the ICC is sample-dependent (De Vet et al., 2006). It is easier to distinguish individuals in a heterogeneous sample than in a sample that is more similar with regard to the characteristic under study. The standard deviations of the ATP measurements were higher than those of the DSD measurements. A larger standard deviation expresses more heterogeneity, and thus a higher ICC can be expected. This study only assessed the reliability and agreement in normally-hearing subjects. Therefore, the measurement errors and ICCs in a sample of hearing-impaired subjects should be investigated by future research.

Experiment 2

The construct validity of the signal detection test is supported by its moderate levels of correlations to most conventional hearing tests, specifically to pure-tone audiometry and the speech reception test performed in fluctuating noise. These results confirm that the ability to detect acoustic warning signals in the acoustic environment of a train cabin is related to an engineer's hearing acuity. It also indicates that conventional hearing tests do not cover the whole construct measured with the signal detection test, which supports the idea that a separate test is required for evaluating the hearing-critical task of detecting auditory warning signals.

Contrary to the moderate association with the SRT in fluctuating noise, we did not find moderate associations with the SRT in continuous noise. Since the only difference between these tests is that the test in fluctuating noise assesses the ability to make use of fluctuations in the noise, and the test in continuous noise does not, this finding suggests that the ability to detect warning signals in train cabin noise is also related to the ability to process temporal effects in either the signal or the noise. It might also be the case that the train noise used is less stationary than we assumed it to be. The lack of a moderate association with the speech reception test in continuous noise could be interpreted as suggesting that the SRT in continuous noise is not suitable to determine if warning signals can be detected.

The results of our study support the recommendation of using a task and job specific test for measuring auditory fitness for job performance (Tufts et al., 2009) since the signal detectability depended on the acoustic characteristics of the background noise. In line with earlier studies (Kurze et al., 2000; Pronello, 2003; Van der Hoek-Snieders et al., 2021), we found that the detectability of a signal could be different when another warning signal or ambient noise spectrum was used. Also, the results suggest that locomotive engineers could better compensate for their hearing loss when detecting the DSD signal than the ATP signal since the engineer's SNR_{50} (experiment 2, Table 2) was only slightly higher compared with the normally-hearing individuals (experiment 1, Table 1) for the DSD signal, but much higher for the ATP signal. Hearing loss may have greater relative effect on the detectability of the ATP signal than on the detectability of the DSD signal. This might be explained by the frequency content of the test signals. The DSD signal contains lower frequencies compared with the ATP signal. Since the hearing loss of the included engineers was mostly a high-frequency loss, this effect is probably due to essential high-frequency components in the ATP signal. The construct validity of the signal detection test could be further assessed by future research, for example with hypotheses regarding the signal detection test and objective hearing-critical aspects of the locomotive engineer job.

The acoustic characteristics of the warning signals in Dutch locomotive cabins do not seem to optimally facilitate engineers in performing their job safely and effectively, especially if hearing loss is present. The most prominent signal peaks of the warning signals include the spectral elements that are commonly affected most strongly by noise-induced hearing loss or age effects, respectively, between 2000 and 4000 Hz and 4000 and 8000 Hz (Van der Hoek-Snieders et al., 2021). We therefore recommend to investigate the possibility to modify the acoustic warning signals to make them more robust against hearing loss and background noise. This can be done, for example, by using broadband signals rather than tonal signals (Nélisse et al., 2011) or by adding more low frequency sound components (ISO, 2003). However, even if such an optimization has been realized, it still remains important to assess an individual locomotive engineer's auditory fitness for job to ensure driving safety and effectiveness. By assessing signal detectability in terms of the SNR_{50}, we made use of a quantitative performance level. This is in line with the recommendation that a measurement used for determining fitness for job must be accessible in terms of a quantitative performance measure to provide fine discrimination between individual performance levels (Payne & Harvey, 2010). The quantitative performance levels can be used to determine a set of standards for the signal detection test, such as minimum standards for job performance in each train type. Eventually, the signal detection test will result in one of the following conclusions: (1) the engineer is capable to safely perform the job, (2) accommodations are needed to safely perform the job, such as hearing aids, or (3) the engineer is incapable to perform the job safely. For drawing these conclusions, future research is required to establish the cut-off points. Precaution is required when hearing aids are required for sufficient signal detectability. Due to the high noise levels in Dutch train cabins, hearing aids should be well limited to avoid over-exposure (Dolan & Maurer, 2000).

The signal detection test under study is task and job specific, but it does not replicate the job task with regard to all job characteristics. The only task of the test is to detect the acoustic signals, rather than combining detecting signals with other tasks, such as driving safely and communicating with others (Zoer et al., 2014). Also, the signal detection test assesses the signals one by one, whereas an engineer should distinguish the DSD and ATP signal during normal operation. Finally, we used an up-down procedure to determine the SNR_{50}, whereas in the real work situation, the warning signals need to be detected at a certain, predefined level. Due to the adaptive two-interval, forced-choice procedure used, the signal detection test differs from locomotive engineer's listening task to detect acoustic warning signals in their working environment. Since the listening intervals are marked by this procedure, and the test subject is forced to choose, the signal detection test results in the most critical SNR_{50} in which the warning signals can be detected. In a real working environment, signals at this SNR will likely not be reliably detected by the engineer. Therefore, it is advised to present signals at least 12 dB higher than the signal level of the measured SNR_{50} (Giguère et al., 2008; Hung & Hétu, 1996).

Although the signal detection test would have even higher face validity when it would replicate all job characteristics, such a test would be unfeasible to administer, especially because the job task under study has a long duration (Beck et al., 2016; Payne & Harvey, 2010). When all job characteristics would have been replicated, this would have resulted in a test setting in which warning signals need to be recognized at the level at which they are normally presented in the train cabin, while the engineers perform a broader driving test. The duration of this test would have been 2.5 hours since this is reported to be the longest consecutive amount of time that a locomotive engineer spends in the train cabin (Zoer et al., 2014). The method used in this study has resulted in a test that is job and task specific as well as easy to administer (Payne & Harvey, 2010). The fact that the signal detection test does only replicate the acoustic environment of a work situation provides opportunities for broader use of the test. By expanding the test with other workplace signals and noises, it could also be used to evaluate the detectability of warning signals in other professional settings that require sufficient signal detectability.

Study limitations

Some study limitations should be noted. First, the sample size of experiment 1 was relatively low, and the study sample of experiment 1 did not include locomotive engineers. Adequate signal detection might be easier for engineers who are familiar with the presented noise environments and warning signals. This might implicate that normal-hearing engineers would achieve even a lower SNR_{50}. However, all participants performed a practice round to get familiar with the noise environment and the signals. All normally-hearing subjects performed the test two times in twelve driving conditions. It can be concluded that there was no learning effect since there was no systematic difference between the first and the second time. Second, only two of the six train types were included in experiment 2. For our study, we have selected the noisiest train type plus the train type that is relevant for most engineers. Our strategy differs from that of other authors, such as Giguère et al. (2019) and Laroche et al. (2014), who consulted job content experts for making this selection. The current signal detection test was developed from an audiological viewpoint. Further evaluation with job content experts could give additional insight in the construct validity. Third, we retrospectively collected data from the auditory fitness for job assessments performed in the Amsterdam UMC, where it is standard procedure to perform the signal detection test in two trains. The use of retrospective data facilitated the data collection of the experiment. Moreover, the experiment was performed in a sample of engineers who had been referred for an auditory fitness for job assessment. Since the signal detection test ultimately aims to improve auditory fitness for job assessments of locomotive engineers, the generalizability of the study results is good. Finally, the laboratory paradigm used might have resulted in underestimating the effect of age, hearing impairment, and comprehension for attention.

Conclusions

Our findings support that the signal detection test has sufficient reliability and agreement in all but three driving conditions. Since six of the seven validity hypotheses were confirmed, the construct validity of the signal detection test is supported for assessing the ability to detect auditory warning signals in Dutch locomotive engineers. The results underpin the importance of evaluating the ability to detect auditory warning signals separately from other auditory tasks.

General discussion

The focus of this thesis is on employees with hearing loss and the difficulties that they face during and after work performance. Therefore, hearing loss is not considered to be an isolated medical problem, but a social cultural phenomenon affecting the hearing function, functioning in everyday activities, and – in particular – work functioning as part of participation in life situations (Danermark et al., 2013; Granberg et al., 2014). Many job tasks need to be performed in complex working environments, such as workplaces with noise and/or reverberation (Soli, Giguère, et al., 2018). Especially in these workplaces, even employees with a mild degree of hearing loss may perceive problems, such as difficulties with communicating, productivity issues, or social withdrawal after work hours (Granberg & Gustafsson, 2021; Kramer et al., 2006).

Although this broader perspective on hearing loss is increasingly acknowledged, it is only sparsely implemented in current research and audiological practices (Granberg & Gustafsson, 2021; Zuriekat et al., 2021). Recently, Zuriekat et al. (2021) conducted interviews with audiologists in the UK to explore their perspectives regarding hearing health care for employees with hearing loss. These audiologists described employees with hearing loss to be 'challenging cases with specific needs'. However, they reported to miss specific information and training to support this group accordingly. The literature is scarce regarding the impact of hearing loss on work functioning, interventions that may be effective for employees with hearing loss, and diagnostic instruments that can be used to assess auditory fitness for job assessment (Granberg & Gustafsson, 2021; Tufts et al., 2009).

In this thesis we have used existing clinical tests, more advanced clinical tests, and questionnaires:

- To explore what hearing-related, personal, and environmental factors influence the difficulties of employees with hearing loss and how these factors interfere with each other;
- To evaluate the effect of current rehabilitation practices measured with tools that are currently used in audiological practice;
- To evaluate tests that can be used to assess the performance of hearing-critical job tasks and to describe the development of a new tool to evaluate the ability to detect auditory warning signals.

Hearing assessment

Assessment of the hearing function

Pure-tone audiometry is widely used for the diagnosis of hearing loss (Fredriksson et al., 2016). Also, auditory inclusion and exclusion criteria for employment are commonly based on pure-tone thresholds (Tufts et al., 2009). It is easy to administer and reliable for the assessment of the hearing function. However, it has been shown to poorly predict other aspects of auditory functioning (Forshaw & Hamilton, 1997; Laroche et al., 2003; Tufts et al., 2009). The same was found in the studies of this thesis. For example, only moderate associates were found between the outcome of pure-tone audiometry and the signal detection test that was developed in chapter 6. The latter shows that the ability to detect auditory warning signals in the ambient noise of a simulated train cabin cannot be accurately predicted with the outcome of pure-tone audiometry. The finding that pure-tone audiometry is a poor predictor of aspects of auditory functioning can be explained by the fact that pure-tone thresholds are established by presenting simple tones, monaurally, in a quiet environment, whereas auditory job tasks often require more complex signals to be heard, such as speech. Frequently, spatial hearing is important and many jobs are performed in environments with noise and/or reverberation. In addition, some workers may and others may not be able to compensate for their hearing loss by relying on other senses (sight, touch), skills, and experience. Therefore, other diagnostic instruments are required to predict the consequences of hearing loss on everyday activities and societal involvement. Although common practice, it does not seem to be adequate to use pure-tone thresholds as the sole criterion to assess the performance of hearing-critical job tasks (Tufts et al., 2009).

Assessment of personal and environmental factors

Coping behavior in adults with hearing loss can be assessed with the CPHI. The Dutch CPHI (Mokkink et al., 2009) has been translated from the American-English version (Demorest & Erdman, 1987). Factor analysis has confirmed the structure of this Dutch questionnaire (Mokkink et al., 2009). This study also describes mean scale scores of 399 adults with hearing loss aged from 20 to 86. The original Dutch CPHI contains 52 questions. Using IRT modelling, a short CPHI form was developed including 35 questions (Lidwine B. Mokkink et al., 2010). This study describes mean scores of an additional 408 adults.

The CPHI can provide a comprehensive overview of the coping behavior that is used by employees with hearing loss. It is hearing-specific, and may therefore be sensitive to detect change in the coping behavior of employees with hearing loss. The results of chapter 3 suggest that this is indeed the case, at least for the personal adjustments subscales, since a significant difference was found in the personal adjustment subscales of 50 employees with hearing loss before and after aural rehabilitation. However, no significant difference was found regarding the communication strategies subscales. It is difficult how to interpret changes in CPHI score, because the longitudinal validity of the questionnaire has not yet been investigated. Also, a qualitative evaluation may be required to interpret CPHI change scores. For example, within the CPHI, little use of verbal coping strategies is interpreted as inadequate. However, using verbal coping strategies may be adequate in some cases, for example if sufficient hearing is accomplished after aural rehabilitation.

Several aspects of the working environment are important to consider in employees with hearing loss, including the amount of noise at the workplace (Granberg & Gustafsson, 2021; Soli, Giguère, et al., 2018). Noise measurements can be performed to assess the amount of noise at the workplace (South, 2013). This is important in workplaces with high noise levels, for example to determine which preventive measures need to be undertaken (Sorgdrager et al., 2006; Tikka et al., 2017). Also, the amount of noise at a workplace can be used to estimate the likelihood of effective speech communication for normally-hearing employees (Houtgast et al., 2002; Soli, Giguère, et al., 2018). For employees with hearing loss, this likelihood can also be predicted, based on the outcomes of pure-tone audiometry and a speech perception test in noise (Soli, Amano-Kusumoto, et al., 2018). However, in workplaces with low or moderate noise levels – such as classrooms – noise measurements are often not available (Dreschler & Boermans, 1997). In chapter 3, it was observed that noise measurements at the workplaces of the included employees were not available. Using the Amsterdam Checklist for Hearing and Work (ACHW), the subjective amount of noise at the workplace was inventoried. The subjective amount of noise reflects employees' individual sensitivity to the background noise present at their workplace (Kramer et al., 2006). To our knowledge, there is no standardized and validated questionnaire to assess the subjective amount of noise at the workplace.

The ACHW also includes questions regarding the auditory demands at the workplace. Specifically, the occurrence of six hearing-related job tasks is inventoried, including communication in noise and detecting (warning) sounds. These questions provide a broad, qualitative overview of the auditory work demands for employees with hearing loss. This part of the ACHW has not yet been standardized nor validated and no reference values are available, but this information has proven to be highly important in clinical use.

Other aspects of the working environment can be assessed with generic questionnaires, such as the Questionnaire on the Experience and Evaluation of Work (QEEW) (Van Veldhoven et al., 2015). The QEEW scales can provide an impression of several aspects of the working environment of employees with hearing loss, such as the relationship with the supervisor or colleagues and the pace and amount of work. Especially when considering the NFR, it seems to be relevant to take the influence of work characteristics into account. For example, in chapter 2, the scales score 'pace and amount of work' and 'work pleasure' were found to significantly explain variations in NFR. The QEEW has been shown to have high content validity and internal consistency and some studies have been performed to assess the longitudinal validity of QEEW scales (Van Veldhoven et al., 2015). Although the QEEW has not been developed nor validated specifically for employees with hearing loss, it can be used to provide a general impression of work characteristics.

Assessment of activities and participation

Hearing tests

Speech audiometry, assessing the perception of monosyllabic words in a quiet listening environment, is often used for clinical or research purposes (Tufts et al., 2009). However, difficulties with speech understanding are particularly experienced in noisy environments. Therefore, speech perception tests in noise are recommended, such as the digits-in-noise test (Smits et al. 2013) and the Occupational Ear Check (OEC) (Sheikh Rashid and Dreschler 2018) for screening purposes. For diagnostic and evaluative purposes, the ability to understand speech in noise at work may even closer be simulated using speech perception tests that contain everyday sentences as speech stimuli, such as the Dutch sentences developed by Plomp and Mimpen (1979), or the VU98 speech material, developed by Versfeld et al. (2000). Also, the outcome of a speech perception test in noise can be used to estimate the impact of hearing loss on speech understanding in a specific work environment (Soli, Amano-Kusumoto, et al., 2018). Although, speech perception tests in noise are increasingly used for research purposes, they are not yet widely used in clinical practices or for assessing the performance on hearing-critical job tasks (Tufts et al., 2009). In the routinely healthcare data that was included for the study described in chapter 1, it was observed that a speech perception test in noise was performed in only half of the employees with hearing loss that visited an audiological center.

Speech perception tests in noise have the potential to be used for specific purposes. First, comparing the performance in continuous noise versus in fluctuating noise provides information about how well an individual is capable of making use of relative silent periods in the noise. This may be relevant, for example, in employees that need to understand incomplete or distorted verbal messages at work, for example when there is a need for communication via radios or walkie-talkies (Cook & Hickey, 2003). Second, speech perception tests can be used to assess speech understanding from multiple directions (Darwin, 2008; Dirks & Wilson, 1969; Gnewikow et al., 2009; Grutters et al., 2007; Ricketts & Henry, 2002; Wagner et al., 2020). Although this method is not yet standardized, this may be particularly relevant in employees that need to understand messages from different directions, for example during business meetings. Third, speech perception tests can be used to evaluate the effect of hearing aids or hearing protectors. Speech perception tests are often performed under headphones, but can also be performed in a free field setting using hearing aids or hearing protectors (Duquesnoy & Plomp, 1983).

During our studies, it was observed that performing a speech perception test in noise is part of routine clinical practices for the assessment of auditory fitness of locomotive engineers (chapter 6), but not for evaluating the effect of a speech reading training (chapter 4). This is understandable, because there is no standardized and validated speech perception test available that combines auditory with visual input that could be used for this purpose. The University Medical Center Utrecht has made video recordings of the sentence material of the speech perception sentences developed by (Versfeld et al., 2000). These recordings have not yet been validated.

Questionnaires

Several generic, health-related quality-of-life questionnaires are available, but most have been shown lack sensitivity in populations with hearing loss (Granberg, 2015). An explanation is that many of these questionnaires do not include communication as a health domain, although communication restrictions are one of the most important consequences of hearing loss. Another difficulty is that there is no consensus about what generic questionnaire should be used in employees with hearing loss. The reported prevalence of generic questionnaires for employees with hearing loss was shown to be extremely low, which was even true for established questionnaires, such as the SF-36 (Ware, 1993) and the Health Utility Index Mark III (HUI3) (Feeny et al., 1995). In the studies of this thesis, we focused on hearing- and/or work-specific questionnaires.

Many hearing-specific questionnaires are available (Bentler & Kramer, 2000; Granberg, 2015), but again, the reported prevalence of these questionnaires is very low (Granberg et al., 2014). This may reflect a lack of consensus regarding the most appropriate questionnaires for adults with hearing loss. At the audiological centers that participated in the studies of this thesis, the Speech, Spatial, and Qualities of hearing scale (SSQ) is used to inventory the extent of listening difficulties during several daily life activities (Gatehouse & Noble, 2004). This questionnaire has been developed and validated for adults with hearing loss, and not specifically for employees with hearing loss.

At the participating centers in the studies of this thesis, the NFR scale from the QEEW (Van Veldhoven & Broersen, 2003) was used to assess the need to recuperate from work-induced fatigue. This scale is easy to administer and the outcome is a predictor of occupational and subjective health problems, such as stress complaints. In chapter 3, the NFR of employees with hearing loss was significantly lower after receiving aural rehabilitation, which suggests that the NFR scale might be sensitive to detect change in employees with hearing loss who receive aural rehabilitation. Although the content validity of the scale is sound, only limited research has been performed regarding the longitudinal validity of the scale.

The Dutch ACHW includes questions that are related to the participation of employees with hearing loss, such as the six questions about the effort and concentration it takes to perform six hearing-related auditory job tasks. The questions have good internal consistency (Kramer et al., 2006; Van der Hoek-Snieders et al., 2020), but the scale has not been standardized and validated. As far as we know, a validated, hearing specific, and work specific questionnaire is currently not available (Granberg & Gustafsson, 2021; Tufts et al., 2009).

Research during clinical practice

Most of the studies in this thesis are performed in the setting of the routine clinical practice of Dutch audiological centers. The audiological center of the Amsterdam UMC, location AMC participated in the studies of chapter 1, 3, and 6, the audiological center of Libra Rehabilitation and Audiology in the studies of chapter 3 and 4, and the audiological center of Adelante Zorggroep in the studies of chapter 4. The participants of these studies completed questionnaires that are also used for clinical purposes. To support the clinical, diagnostic, and rehabilitative processes of the included employees with hearing loss, we provided a practical overview of individual questionnaire outcomes for clinical purposes. This 'hearing and work profile' was used by the clinicians of all participating audiological centers.

The hearing and work profile

The hearing and work profile is a visual summary of the questionnaires that were completed for the studies of this thesis. The purpose of this profile is to support clinicians in the diagnostic and rehabilitative process of employees with hearing loss. It provides a quick impression of the complaints experienced by an employee and several hearing-related and work-related factors that may influence these complaints. Questionnaire scale scores are visualized in a uniform way: as percentages of the maximum score and high scores can be interpreted as unfavorable. This facilitates quick interpretation of the different questionnaires.

The hearing and work profile contains five figures. In the first figure, the responses on the ACHW questions regarding the auditory demands and the listening effort at the workplace are summarized (Figure 1). In the second figure, the SSQ scale scores are summarized (Figure 2). In the third figure, the scale scores of the CPHI scales are visualized as well as three scales of the QEEW, respectively the scales need for recovery, work participation, and relationships with colleagues (Figure 3). The last two figures summarize the responses on the ACHW regarding the job activities that are most frequently performed (Figure 4) and the workplaces that are most frequently used (Figure 5).

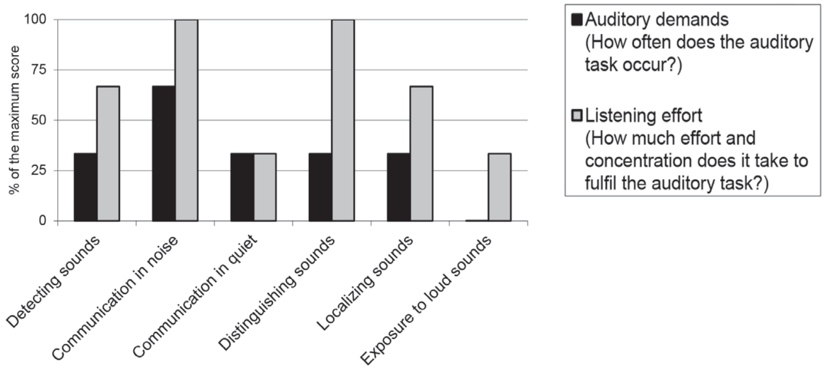

Figure 1. Example of a summary of the answers of an employee with hearing loss to the Amsterdam Checklist for Hearing and Work questions regarding the auditory work demands and the listening effort at work. Answers to the questions are converted to percentages of the maximum score with higher scores representing more unfavorable scores.

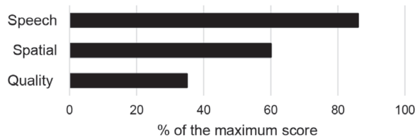

Figure 2. Example of a summary of the answers of an employee with hearing loss to the Speech, Spatial, and Qualities of hearing scale. The scale scores (mean scores of the questions belonging to each scale) are converted to percentages of the maximum score with higher scores representing more unfavorable scores.

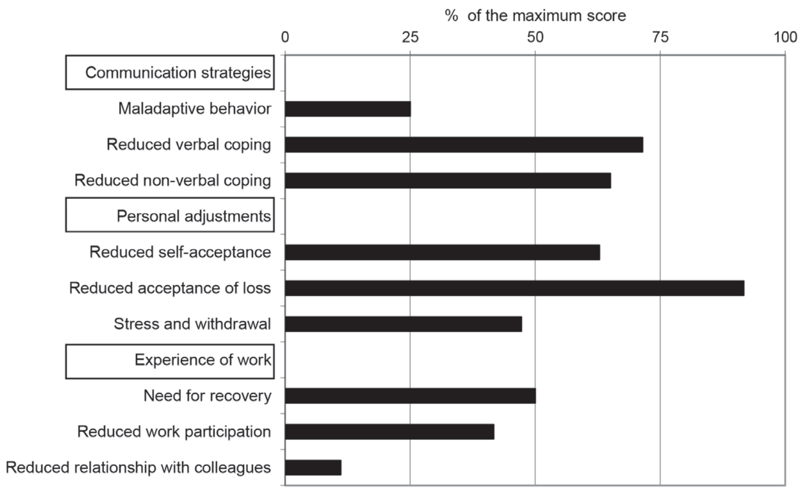

Figure 3. Example of a summary of the answers of an employee with hearing loss to the Communication Profile of the Hearing Impaired (CPHI) scale scores and three scale scores of the Questionnaire on the Experience and Evaluation of Work (QEEW). The scale scores are converted to percentages of the maximum score with higher scores representing more unfavorable scores.

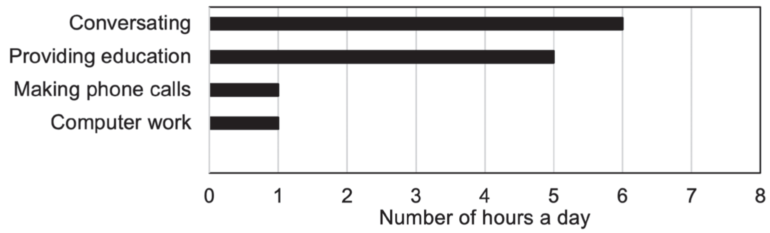

Figure 4. Example of a summary of the answers of an employee with hearing loss to the to the Amsterdam Checklist for Hearing and Work questions regarding the job activities that are most frequently performed.

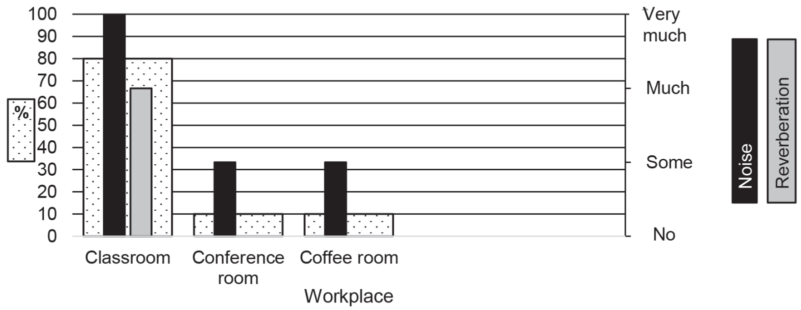

Figure 5. Example of a summary of the answers of an employee with hearing loss to the to the Amsterdam Checklist for Hearing and Work questions regarding the workplaces that are most frequently used.

Part I: Factors influencing professional functioning

The model that is proposed in chapter 1 and confirmed in chapter 3 provides insight into the hearing-related, work-related, and personal factors that directly and indirectly influence the Need For Recovery (NFR) and Listening Effort (LE) of employees with hearing loss. According to the model, the constructs NFR and LE partly overlap, and both are influenced by the factors 'feeling that something should change at work' and personal adjustments (PA). This finding suggests that the influence of hearing loss on work functioning seems to depend on the way employees perceive their hearing loss and how they cope with it.

On the other hand, the association between the outcomes of hearing tests and NFR was not that strong, a finding that was also found in a non-clinical population (chapter 2). This was true regarding the outcomes of pure-tone audiometry, speech audiometry, and a speech perception test in noise. The associations between the outcomes of these hearing tests and LE were significant and stronger, although still only moderate. Since the majority of the study population had a moderate degree of hearing loss, this finding suggests that the influence of hearing loss on work functioning does not depend on small differences in the measured degree of hearing loss.

These findings imply that for the diagnosis of employees with hearing loss, only performing hearing tests does not suffice. It seems to be important to consider how employees perceive their hearing and their functioning, as well as how they cope with associated difficulties.

Part II: Evaluation of professional functioning

The study in chapter 3 is the first study showing that the NFR of employees with hearing loss can significantly improve after aural rehabilitation, although the NFR of only part of the employees was improved. Therefore, there seems to be a need to enhance aural rehabilitation practices to accomplish a greater effect on work functioning in employees with hearing loss. Since the change in NFR and LE could significantly be explained by the change in PA, interventions stimulate effective use of PA might be effective for this purpose.

In chapter 4, communication group-trainings were under study. These interventions were hypothesized to be effective to improve the PA and the Communication Strategies (CS) of employees with hearing loss, which might also result in improvement of the NFR of these employees. Due to the COVID-19 pandemic, many communication group-trainings were cancelled, which resulted in the inclusion of only 9 employees. Therefore, the statistical power of this study is relatively low. Nevertheless, the descriptive results showed that most employees used more adequate CS after the group-training and pointed out to differences in the improvement in PA between the centers. However, no trend towards improvement in the NFR was observed.

The results of these studies show that it is still challenging to reduce the difficulties in work functioning encountered by employees with hearing loss. Employees may benefit from a broader intervention that combines sensory management interventions with instruction and counselling, but the effective ingredients of aural rehabilitation remain unclear. There is a need for knowledge on what rehabilitation strategies can be used effectively to reduce the difficulties in professional functioning of employees with hearing loss. For example, the effect of the different rehabilitation components should be investigated, the effect of interventions that affect the working environment, and the optimal intensity and duration of these intervention. Therefore, there is a great need for high quality intervention studies, such as randomized controlled trials with a sufficient sample size. In particular, we recommend the investigation of interventions that focus on optimizing the use of PA and interventions that focus on work adjustments. Our results suggest that extra effort in this area may be promising.

A limitation of the studies of chapter 1, 2, 3, and 4 is that some measurements were used with low measurement quality. We had to deal with the lack of valid instruments that can be used for the diagnosis and evaluation of aspects of work functioning in employees with hearing loss (Granberg & Gustafsson, 2021; Tufts et al., 2009). Psychometric research is required of questionnaires that can be used for research, the diagnosis, and evaluation of employees with hearing loss. For example, the NFR scale may be validated for the diagnosis and evaluation of work-induced fatigue in the population of employees with hearing loss. Also, the LE and auditory demands scale may be standardized and validated for the same population. Another limitation of our studies is that some potential effects of aural rehabilitation could not be investigated. The effect of speech reading training on speech perception could not be evaluated with a behavioral test, because there is no validated audio-visual speech perception test in noise available in Dutch. The effect of sensory management interventions on speech understanding could also not be evaluated with a clinical test, because speech perception tests were only sparsely used for aided measurements in a free field condition.

Part III: Measuring hearing-critical job tasks

For locomotive engineers, detecting acoustic warning signals is crucial for safe and effective job performance. The results of chapter 5 show that Dutch locomotive engineers need to detect these signals in a challenging acoustic environment making this task hearing-critical. Since detection of the Automatic Train Protection (ATP) signal often depends on the detection of high frequency signal peaks, especially at higher speed, at higher speed, the detection of this signal is critical for employees with a high-frequency loss.

In chapter 6, the development and validation of a signal detection test for Dutch locomotive engineers is described. The test was found to have sufficient reliability and agreement in most driving conditions and hypotheses testing supported the construct validity of the test. Moderate associations were hypothesized and confirmed between the outcomes of traditional hearing tests and the signal detection test. This finding implies that ability to detect warning signals in train noise is not reflected well by traditional hearing tests. This underlines the importance of performing more advanced tests to assess auditory fitness of locomotive engineers.

The signal detection test described in chapter 6 also requires further development and validation. Specifically, a cut-off for safe detection of the signals has not yet been established. Although the signal detection test is task and job specific, it does not include all work characteristics. For example, the cognitive complexity of driving is not investigated during the test. Therefore, a cut-off for safe driving would be based on a theoretical estimation and a safety margin. Also, to keep the test up-to-date, new measures are required with new trains. For example, the Mat64 is no longer in use. Also, there are trains with potentially higher noise levels than in the trains under study, such as in high-speed trains. Therefore, the worse-case cannot yet be investigated. Lastly, the approach and test design of the signal detection test may have the potential to be useful for the assessment of auditory fitness for job performance in other occupations.

Implications for clinical practice

The studies of this thesis have shown that hearing loss impacts on work functioning in different ways. Employees with hearing loss may face difficulties with fulfilling auditory job tasks or with recuperating from work-induced fatigue. The difficulties deserve to be adequately recognized, diagnosed, rehabilitated (if possible), and counselled. Also, the effects of treatment need to be evaluated.

Improving the awareness of employees ánd employers about hearing loss and its potential impact on work functioning may help for early recognition of employees with hearing loss. Hearing screening can raise awareness about hearing loss (Smits & Houtgast, 2005) and may serve for this purpose. At this moment, screening is routinely performed in employees that are exposed to excessive noise levels at their workplace (Sorgdrager et al., 2006). However, since hearing loss is not only caused by noise, employees working in workplaces without high noise exposure may also benefit from routinely screening.

Occupational physicians can also contribute to early recognition of hearing loss. In line with the protocol of the Dutch Board for Occupational Medicine (NVAB) entitled 'hearing loss and tinnitus', we advocate alertness for hearing loss as an underlying cause of increased NFR and associated occupational and health problems. Occupational physicians should perform a hearing screening in employees that present with psychological complains, such as complaints about fatigue, depression, anxiety, or burn-out. In case of a suspicion work functioning difficulties due to hearing loss, even if the hearing loss is expected to be mild, the employee should be referred to an audiological center for extensive audiological assessment.

The studies in this thesis add to the body of evidence suggesting that the outcome of traditional hearing assessments are only a poor predictor of work functioning difficulties (Forshaw & Hamilton, 1997; Laroche et al., 2003; Tufts et al., 2009). Therefore, we recommend to not suffice with pure-tone audiometry for the diagnosis of employees with hearing loss or for assessment of auditory fitness. Further assessment is required, including other tests, such as speech perception tests in noise, and questionnaires.

The results described in chapter 3 and 4 point out to a potential benefit of aural rehabilitation. We believe that a broad and multidisciplinary protocol for aural rehabilitation should be accessible for all employees with hearing loss. For example, an audiologist, occupational physician, social worker, and a speech therapist may be involved. Also, explicit support for using adequate PA may be useful, as well as educating employers and colleagues, and stimulating work adjustments.

Measuring the effects of aural rehabilitation primarily of importance for evaluation of the individual results, but is also is important to be able to showing the additional value of aural rehabilitation to health care insurance companies and to improve the quality of aural rehabilitation services. A first step towards validly and uniformly evaluating the effects of aural rehabilitation would be to perform aided measurements and questionnaires after finishing the aural rehabilitation. For example, the SSQ, ACHW, and QEEW could be used.

Conclusions

The studies in this thesis provide insight into several aspects of work functioning in employees with hearing loss. Although hearing loss can be an important underlying cause of difficulties with work functioning, such as higher need for recovery (NFR), these difficulties cannot be quantified nor qualified by solely measuring the degree of hearing loss using the conventional pure-tone audiogram. For the ICF diagnosis of employees with hearing loss, it has been shown that it is important to consider how employees perceive their hearing, their job, and their functioning, as well as how they cope with associated difficulties.

This broad approach should also guide aural rehabilitation practices. It has been shown that the NFR of employees with hearing loss can be improved by aural rehabilitation, although the NFR improved in only part of the employees. Interventions that focus on optimizing coping behaviour may be promising to improve the effects of the rehabilitation. Also, the involvement of employers and colleagues in the aural rehabilitation deserves further attention.

More advanced tests should be used to assess the performance of auditory, hearing-critical job tasks. These tests are available to assess speech communication, but not to assess the detection of auditory warning signals. Therefore, an advanced signal detection test is proposed to assess this ability in locomotive engineers. Hopefully, this thesis will inspire clinicians and researchers to provide and validate rehabilitation services for employees with hearing loss to support their functioning and participation at work.

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List of abbreviations

AC	audiological center
ACHW	Amsterdam checklist for hearing and work
ATP	automatic train protection
BHI	binaural hearing impairment
CPHI	communication profile for the hearing impaired
CS	communication strategies
CVC	consonant-vowel-consonant
dB	decibel
dBA	decibel A-weighted
dB HL	decibel hearing level
dB SPL	decibel sound pressure level
DSD	driver's safety device
HA	hearing aid
Hz	hertz
ICC	intraclass correlation coefficient
ICF	international classification of functioning, disability, and health
ICM	*InterCity Materieel* (Dutch train type)
LE	listening effort
L_{Aeq}	the A-weighted sound pressure level
LoA	limits of agreement
LOC1800	*Locomotief 1800* (Dutch train type)
Mat'64	*Materieel64* (Dutch train type)

$Mean_{diff}$	mean difference between two assessments
mDDm	*Motorrijtuig DubbelDeks Materieel* (Dutch train type)
Ms	millisecond
NFR	need for recovery
NVAB	Nederlandse vereniging voor arbeids- en bedrijfsgeneeskunde
OAE	otoacoustic emissions
OEC	occupational ear check
PA	personal adjustments
QEEW	questionnaire on the experience and evaluation of work
SD	standard deviation
SDC	smallest detectable change
SD_{diff}	standard deviation of the mean difference
SEM	standard error of measurement
SNR	signal-to-noise ratio
SNR_{50}	signal-to-noise ratio at which 50 percent of the warning signals can be detected
SRT	speech reception threshold
SPSS	statistical package for social sciences
SSQ	speech spatial and qualities of hearing scale
UMC	university medical center
V-IRM	*Verlengd InterRegio Materieel* (Dutch train type)
WA	work adjustments

Summary

Hearing loss can affect work functioning. For example, employees with hearing loss may experience higher levels of listening effort during the performance of auditory job tasks, may have higher need for recovery after work, or may not be able to fulfill hearing-critical job tasks.

Part I: Factors influencing professional functioning

Following an explorative approach, a model was proposed in **chapter 1** of factors influencing the need for recovery and listening effort of employees with hearing loss. For this study, routine health care data were analyzed of 294 employees who were referred to the ENT-Audiology department of the Amsterdam UMC by their occupational physician. In total, 43 percent of the variance in listening effort could be explained by four factors, respectively 'the feeling that something should change', the degree of hearing loss (binaurally, calculated based on pure-tone audiometry thresholds), auditory work demands, and personal adjustments (part of hearing-related coping behavior). Regarding the factors directly influencing the need for recovery, also four factors were identified. In total, 46 percent of the variance in the need for recovery could be explained by the factors listening effort, 'feeling that something should change at work', personal adjustments and the general health condition. The outcomes of hearing tests were not significantly associated with the need for recovery. This suggests that the way employees perceive their hearing loss and how they cope with it directly influence need for recovery, rather than their measured degree of hearing loss. In **chapter 3**, the associations of the model proposed in **chapter 1** was confirmed in a different population of employees with hearing loss.

In **chapter 2,** we further zoomed into the association between hearing, listening effort, and need for recovery. This study was performed in a non-clinical population of 143 employees of a manufacturing company. Part of the employees were exposed to occupational noise and the noise level differed between the employees. The aim was to assess the association between the hearing status, listening effort and need for recovery, as well to examine whether these associations depend on the perceived noise level at the workplace. Hearing status was measured with the Occupational Ear Check, an internet-based hearing-in-noise test. Regression analyses revealed that

hearing status was significantly associated with listening effort, but the interaction between hearing status and the subjective noise level was not. Hearing status nor the interaction between hearing status and the subjective noise level were significantly associated with NFR. Therefore, the Occupational Ear Check is expected to be unable to predict subjective listening difficulties at the workplace at an individual level. The predictive value of the occupational ear check for high need for recovery is expected to be even poorer. It was concluded that the value of occupational hearing screening appears to be early identification of hearing loss in employees, but not identification work functioning difficulties.

Part II: Evaluation of professional functioning

In **chapter 3**, we evaluated the need for recovery and listening effort of employees before and after they received aural rehabilitation at an audiological center using tools that are currently used in audiological practice. A total of 50 employees completed a questionnaire before and after receiving aural rehabilitation. Both outcomes significantly improved on group level, although improvement was only accomplished in part of the employees. Hierarchical multiple regression analyses revealed that the change in the need for recovery could best be explained by change in personal adjustments, but also by change in listening effort and self-reported hearing ability. Change in listening effort was significantly associated with change in personal adjustments, auditory work demands, and self-reported hearing ability. It was concluded that improving current practices should be considered and evaluated, for example by applying a different combination of rehabilitation components. It was suggested that interventions that stimulate the use of effective personal adjustments may be promising to further reduce the need for recovery of employees with hearing loss.

The use of personal adjustments and communication strategies was hypothesized to improve after a communication group-training which might also result in a reduction of the need for recovery. In **chapter 4**, we therefore evaluated the personal adjustments, need for recovery and communication strategies of employees with hearing loss before and after a communication group-training. The communication training of the two participating was different, for example with respect to the duration and the content of the training. Nine employees were included at two audiological centers and completed a questionnaire before and directly after a communication group training. Descriptive results were provided, because the number of included employees was too small to run statistical analyses. Most employees used more adequate communication strategies after the group-training, but there seems to be a difference between the improvements in personal adjustments between the centers. No trends towards a decrease in NFR was observed. It was concluded that it is still challenging to reduce the work difficulties of employees with hearing loss.

Part III: Measuring hearing-critical job tasks

To perform their job safely and effectively, locomotive need to detect two auditory warning signals in a train cabin, respectively a bell-like signal (the automatic train protection system) and a buzzer-type signal (the driver's safety device). Depending on the acoustic characteristics of the warning signals and the noise in train cabins, detection of warning signals can be a hearing-critical job tasks. Therefore, in **chapter 5** we specified the acoustic characteristics of the warning signals and the noise present in Dutch train cabins. The effectiveness of the warning signals was evaluated when presented to normally-hearing locomotive engineers. It was concluded that the acoustical requirements for signal detectability were not met in all driving conditions. Therefore, difficulties with detecting the signals can be expected, especially in unfavorable driving conditions or in employees with hearing loss, especially in the high frequencies.

In **chapter 6**, the development and validation of a task and job specific signal detection test for Dutch locomotive engineers is described. This test can be performed in twelve driving conditions, respectively with two warning signals and six noise environments. In an experiment with twelve normally-hearing individuals, the reliability and agreement of the test was found to be sufficient in most driving conditions. To assess the construct validity of the test, seven a priori formulated hypotheses were tested with a retrospective analysis of 83 locomotive engineers who were suspected of having hearing loss. They completed the signal detection test, pure-tone audiometry, and two speech perception tests in noise, and rated the effort and concentration it takes to detect the auditory signals at work. Six of the seven hypotheses were confirmed. The results of the signal detection test correlated moderately with the pure-tone thresholds and the speech reception threshold in fluctuating noise, but not with the speech reception threshold in continuous noise. Also, poorer test scores were obtained by hearing aid users compared with non-hearing aid users. It was concluded that evidence was provided supporting the

construct validity of the signal detection test. Also, it was argued that the moderate associations with conventional hearing tests show that the conventional hearing tests did not cover the whole construct measured with the signal detection test. This underpins the importance of evaluating the ability to detect auditory warning signals separately from other hearing-critical job tasks.

Samenvatting

Gehoorverlies kan het functioneren op werk beïnvloeden. Zo kunnen werkenden met gehoorverlies meer luisterinspanning ervaren tijdens het uitvoeren van auditieve taken op het werk, kunnen zij een hogere herstelbehoefte hebben na werk, of kunnen zij problemen ervaren met het uitvoeren van gehoorkritische taken.

Deel I: Factoren die invloed hebben op het functioneren op werk

In **hoofdstuk 1** werd na exploratief onderzoek een model voorgesteld van factoren die de herstelbehoefte en luisterinspanning van werkenden met gehoorverlies beïnvloeden. Voor dit onderzoek werden reguliere patiëntdata geanalyseerd van 294 werkenden die door hun bedrijfsarts waren doorverwezen naar de afdeling KNO-Audiologie van het Amsterdam UMC. In totaal kon 43 procent van de variatie in luisterinspanning worden verklaard door vier factoren, namelijk het gevoel dat iets moet veranderen op het werk, de mate van gehoorverlies (binauraal, berekend op basis van toondrempelaudiometrie), auditieve eisen op het werk en persoonlijke aanpassingen (onderdeel van gehoorgerelateerd copinggedrag). Er werden ook vier factoren geïdentificeerd die de herstelbehoefte direct beïnvloeden. In totaal kon 46 procent van de variatie in herstelbehoefte worden verklaard door de luisterinspanning, het gevoel dat iets moet veranderen op het werk, persoonlijke aanpassingen en de algehele gezondheidstoestand. De uitkomsten van gehoortesten waren niet significant geassocieerd met de herstelbehoefte. Dit suggereert dat herstelbehoefte niet wordt beïnvloed door de ernst van het gehoorverlies, maar de manier waarop werkenden hun gehoorverlies ervaren en hiermee omgaan. De relaties van het model uit **hoofdstuk 1** zijn in **hoofdstuk 3** bevestigd, in een andere populatie van werkenden met gehoorverlies.

In **hoofdstuk 2** werd verder ingezoomd op de relaties tussen de gehoor, luisterinspanning en herstelbehoefte. Deze studie werd uitgevoerd in een niet-klinische populatie van 143 werknemers van een productiebedrijf. Een deel van de werknemers werd blootgesteld aan lawaai op het werk en het lawaainiveau varieerde tussen de werknemers. Het doel was om de relaties te onderzoeken tussen de gehoorstatus, luisterinspanning en herstelbehoefte, en of deze relaties afhankelijk zijn van het ervaren lawaainiveau op het werk. Het gehoor werd gemeten met de Bedrijfsoorcheck, een online spraak-in-ruistest. Regressieanalyses lieten zien dat de gehoorstatus significant geassocieerd was met de luisterinspanning, maar de interactie tussen gehoorstatus en het ervaren lawaainiveau op het werk niet. De gehoorstatus noch de interactie tussen gehoorstatus en het ervaren lawaainiveau op het werk waren significant geassocieerd met de herstelbehoefte. Daarom wordt verwacht dat de Bedrijfsoorcheck niet in staat is om subjectieve luisterproblemen op het werk te voorspellen op individueel niveau. De voorspellende waarde van de Bedrijfsoorcheck voor een hoge herstelbehoefte wordt nog lager ingeschat. Er werd geconcludeerd dat de waarde van beroepsmatige gehoorscreeningen het vroegtijdig herkennen van gehoorverlies bij werkenden lijkt te zijn, maar niet het identificeren van problemen in het functioneren op het werk.

Deel II: Evaluatie van professioneel functioneren

In **hoofdstuk 3** werden de herstelbehoefte en luisterinspanning van werkenden geëvalueerd voor en nadat zij hoorrevalidatie kregen op een audiologisch centrum met tools die momenteel gebruikt worden in de klinische, audiologische praktijk. In totaal vulden vijftig werkenden een vragenlijst in voor en na de hoorrevalidatie. Hoewel slechts een deel van de werkenden verbetering liet zien verbeterden beide uitkomsten significant op groepsniveau. Hiërarchische, multiple regressieanalyse liet zien dat de verandering in de herstelbehoefte het best verklaard kon worden door verandering in de persoonlijke aanpassingen, maar ook door verandering in de luisterinspanning en het subjectieve gehoorvermogen. Verandering in luisterinspanning was significant geassocieerd met verandering in persoonlijke aanpassingen, auditieve eisen op het werk, en het subjectieve gehoorvermogen. Er werd geconcludeerd dat het verbeteren van de huidige zorg overwogen en geëvalueerd zou moeten worden, bijvoorbeeld door een andere combinatie van revalidatiecomponenten toe te passen. Interventies die effectief gebruik van persoonlijke aanpassingen stimuleren werden aangeduid als veelbelovend om de herstelbehoefte van werkenden met gehoorverlies verder te laten dalen.

Er werd verondersteld dat het gebruik van persoonlijke aanpassingen en communicatiestrategieën zou verbeteren na een communicatietraining in een groep, wat mogelijk ook zou leiden tot een daling van de herstelbehoefte. In **hoofdstuk 4** evalueerden we daarom de persoonlijke aanpassingen, herstelbehoefte en communicatiestrategieën van werkenden met gehoorverlies voor en nadat zij een communicatietraining volgden in een groep. De communicatietrainingen van de twee deelnemende centra verschilden onder andere wat betreft de duur en de inhoud van de training. Negen werkenden werden geïncludeerd bij twee audiologische centra en vulden een vragenlijst in voor en direct na de communicatietraining. Er werd beschrijvende statistiek gebruikt, omdat het aantal werkenden te klein was om statistische analyses uit te voeren. De meeste werkenden gebruikten meer adequate communicatiestrategieën na de communicatietraining, maar er leek een verschil te zijn tussen de centra wat betreft de verbetering in de persoonlijke aanpassingen. Er werd geen trend gezien in de richting van een daling van de herstelbehoefte. Er werd geconcludeerd dat het nog uitdagend is om de problemen op het werk te verminderen van werkenden met gehoorverlies.

Deel III: Meten van gehoorkritische taken

Machinisten moeten twee auditieve signalen kunnen detecteren in een treincabine om hun werk veilig en effectief uit te voeren, namelijk een bel (het signaal van het automatische treinbeïnvloedingssysteem) en een zoemer (het dodemanssignaal). Afhankelijk van de akoestische karakteristieken van de waarschuwingssignalen en het lawaai in treincabines kan signaaldetectie een gehoorkritische taak zijn. Daarom hebben we in **hoofdstuk 5** de akoestische karakteristieken gespecificeerd van de waarschuwingssignalen en het lawaai dat aanwezig is in Nederlandse treincabines. De effectiviteit van de waarschuwingssignalen is geëvalueerd voor machinisten met een normaal gehoor. De conclusie was dat er niet in alle rijomstandigheden werd voldaan aan de akoestische voorwaarden voor signaaldetectie. Daarom kunnen moeilijkheden worden verwacht met het horen van waarschuwingssignalen, met name onder ongunstige rijomstandigheden en/of bij machinisten met gehoorverlies, zeker in de hoge frequenties.

In **hoofdstuk 6** wordt de ontwikkeling en validatie beschreven van een taak- en beroepsspecifieke signaaldetectietest voor Nederlandse machinisten. De test is uitgevoerd in twaalf rijcondities, namelijk met twee waarschuwingssignalen en in het lawaai van zes treincabines. In een experiment met twaalf normaalhorenden werden de betrouwbaarheid en overeenstemming van de test voldoende bevonden in de meeste rijcondities. Om de constructvaliditeit van de test te onderzoeken werden zeven hypotheses a priori getoetst met een retrospectieve analyse van 83 machinisten met vermoedelijk gehoorverlies. De machinisten voerden de signaaldetectietest uit, toonaudiometrie en twee spraaktesten in ruis, en ze gaven aan hoeveel moeite en concentratie het hen kost om waarschuwingssignalen te detecteren tijdens hun werk. Zes van de zeven hypotheses werden bevestigd. De resultaten van de signaaldetectietest correleerden matig met de uitkomsten van de toonaudiometrie en de spraaktest in fluctuerende ruis, maar niet met de uitkomst van de spraaktest in continue ruis. Daarnaast scoorden hoortoestelgebruikers slechter op de test dan niet-hoortoestelgebruikers. Er werd geconcludeerd dat de resultaten de constructvaliditeit van de signaaldetectietest ondersteunen. Daarnaast werd beargumenteerd dat de matige relaties met conventionele gehoortesten laten zien dat conventionele gehoortesten niet hetzelfde meten als wat er wordt gemeten met de signaaldetectietest. Dit onderschrijft het belang van het apart meten van het vermogen om signalen te kunnen detecteren van andere gehoorkritische taken.

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Publications

Journal articles included in this thesis

Van der Hoek-Snieders, H.E.M., Boymans, M., Sorgdrager, B., & Dreschler, W.A. (2020). Factors influencing the need for recovery in employees with hearing loss: a cross-sectional study of health administrative data. *International Archives of Occupational and Environmental Health, 93*, 1023-1035.

Van der Hoek-Snieders, H.E.M., Boymans, M., Sorgdrager, B., & Dreschler, W.A. (2020). Correction to: Factors influencing the need for recovery in employees with hearing loss: a cross-sectional study of health administrative data. *International Archives of Occupational and Environmental Health, 93*(8), 1037.

Van der Hoek-Snieders, H.E.M., Houben, R., & Dreschler, W.A. (2021). Detectability of auditory warning signals in the ambient noise of Dutch train cabins. *Ergonomics, 64*(4), 474-484.

Van der Hoek-Snieders, H.E.M., Houben, R., & Dreschler, W. A. (2021). Measuring Auditory Fitness in Locomotive Engineers: Development and Validation of a Signal Detection Test. *Ear and Hearing, 42*(5), 1313-1320.

Van der Hoek-Snieders, H.E.M.., Boymans, M., & Dreschler, W.A. (2022). Factors associated with change in the need for recovery and subjective listening effort in employees with hearing loss receiving aural rehabilitation. *International Archives of Occupational and Environmental Health,* 1-13.

Van der Hoek-Snieders, H.E.M., Boymans, M., & Dreschler, W.A. (2023). Communication strategies, personal adjustments, and need for recovery in employees with hearing loss who receive a communication group-training. *Hearing, Balance and Communication,* accepted for publication.

Van der Hoek-Snieders, H.E.M., De Laat, J.A.P.M., & Dreschler, W.A. (2023). The relationship between hearing status, listening effort, and the need for recovery in employees of a manufacturing company. *European Archives of Oto-Rhino-Laryngology*, under review.

Other publications

Van der Hoek-Snieders, H.E.M., Stegeman, I., Smit, A. L., & Rhebergen, K. S. (2020). Linguistic Complexity of Speech Recognition Test Sentences and Its Influence on Children's Verbal Repetition Accuracy. *Ear and Hearing*, 41(6), 1511-1517.

Van der Hoek-Snieders, H.E.M., van den Heuvel, A. J., van Os-Medendorp, H., & Kamalski, D. (2020). Diagnostic accuracy of fetal MRI to detect cleft palate: a meta-analysis. *European Journal of Pediatrics, 179*(1), 29-38.

Van der Hoek-Snieders, H.E.M., Lijten, I.J., van Klaveren, E.E., Jansen-Spit, S., & Bruinsma, G. (2021). Voorzetselgebruik van kinderen met TOS: Een vergelijking met zich normaal ontwikkelende kinderen. *Nederlands Tijdschrift voor Logopedie, 93*(2), 18-26.

Van der Hoek-Snieders, H.E.M., Rhebergen, K.S. (2023). Research note: Exploring the Sentence Length and Age of Acquisition of Speech Recognition Test Sentences in Dutch, American English, and Canadian French. *Journal of Speech, Language, and Hearing Research,* accepted for publication.

Curriculum vitae

Hanneke van der Hoek-Snieders was born on the 25th of May, 1993 in Veldhoven. She obtained two secondary school diplomas at Rythoviuscollege Eersel, respectively 'the mavo' in 2009 and the 'the havo' in 2011. Subsequently, she studied Speech and Language therapy at Hogeschool Utrecht and graduated in 2015 (cum laude). After graduation, she started working at Logopedie Lingua in Nieuwegein, a speech and language therapy practice that has specialized in the treatment of young children. Until 2018, she combined this with the part-time master Clinical Health Sciences at the University of Utrecht. During her master's thesis entitled 'The linguistic complexity of speech recognition test sentences and its Influence on children's verbal repetition accuracy' she became intrigued by the field of audiology and her potential role in that field. In 2018, she obtained her Master of Science degree (cum laude). After graduation, she combined her work as a speech therapist with her new assignment as a PhD student at the ENT-Audiology department of the Amsterdam University Medical Center, AMC location and she is also a teacher of a postgraduate course for speech and language therapists. As of January 2023, she works as a speech and language therapist at the University Medical Center Utrecht where she contributes to the multidisciplinary diagnosis of children with speech and language difficulties and where she is involved in the rehabilitation of children with hearing loss.

Portfolio

	Year	ECTS
Courses		
- The Amsterdam UMC World of Science	2018	0.7
- E-BROK ('Basiscursus Regelgeving Klinisch Onderzoek')	2019	1.5
- Citation analysis and impact Factors	2019	0.1
- Student coaching	2019	0.5
- Talents in PhD	2022	0.4
- Didactical skills	2019	0.4
- Clinimetrics: Assessing Measurement Properties of Health Measurement Instruments	2019	0.6
- Writing a scientific paper	2020	1.5
- Peer to peer group coaching	2020	1.5
- Re-registration BROK	2022	0.5
Seminars, workshops and master classes		
- Department research meetings	2018-2022	1.0
- Minisymposium HORA EST, Amsterdam	2018	0.1
- Meetings Nederlandse Vereniging van Audiologie	2018-2022	0.6
Presentations		
- *'Development of a simulation test for locomotive engineers' (poster)*, Arches meeting, Nottingham, United Kindom	2018	0.5
- *'Need for recovery in hearing-impaired employees'*, ARCHES meeting, Paris, France	2019	0.5
- *'Hearing loss, work, and need for recovery'*, Meet the author meeting by Logoscientia (online)	2021	0.5
- *'Factors associated with a decrease in the need for recovery in hearing-impaired employees receiving aural rehabilitation', ARCHES meeting'*, Amsterdam, the Netherlands	2022	0.5
- *'Auditory functioning in locomotive engineers'*, network meeting for hearing care professionals at Libra Revalidation and Audiology, Eindhoven, the Netherlands	2022	0.5
- *'Need for recovery, listening effort, and coping before and after aural rehabilitation at an audiological center'*, internal scientific lunch meeting at Libra Revalidation and Audiology (online).	2022	0.5
(Inter)national conferences		
- ARCHES meeting, Nottingham, United Kingdom (including presentation)	2018	0.5
- Hearing well and being well – a strong scientific connection, Frankfurt, Germany (participant)	2019	0.8
- ARCHES meeting, Paris, France (including presentation)	2020	0.5
- ARCHES meeting, online (participant)		
- Hearing well is being well- a strong scientific connection, online (participant)	2021	0.5
- ARCHES meeting, Amsterdam, the Netherlands (including presentation)	2022	0.5
Lecturing		
- Course 'research skills' for medical students	2020-2021	1.0
- Course 'Communicatieve taaltherapie voor kinderen met een taalniveau van 2 tot 6 jaar' for speech therapists	2018-2022	4.0