Université de Montréal

Acclimatation aux appareils auditifs par les personnes âgées avec perte auditive

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Résumé

Les aides auditives (AA) sont les principaux outils d'intervention de réadaptation recommandés aux personnes âgées ayant une perte auditive, car elles offrent un large éventail d'avantages. Cependant, beaucoup de personnes qui possèdent des AA ne les utilisent pas ou les sous-utilisent. La raison la plus récurrente exprimée par ces non-utilisateurs d'AA est la difficulté persistante à comprendre les conversations dans des environnements bruyants. Il n'est pas mentionné si ces personnes ont essayé de porter leurs AA pendant un certain temps avant de décider de ne plus les porter. Dans l'éventualité où elles auraient abandonné peu de temps après l'obtention de leurs AA, il est possible que ces individus n'aient pas bénéficié d'une adaptation optimale à l'environnement sonore, appelée *acclimatation auditive*. L'objectif principal de cette thèse est d'évaluer l'apport de l'expérience avec les AA sur l'acclimatation auditive.

La première étude visait à déterminer, au moyen d'une revue systématique, si un effet d'acclimatation se produit après l'utilisation d'AA et, le cas échéant, à établir l'amplitude et l'évolution dans le temps de cet effet. Quatorze articles évaluant l'acclimatation via des mesures comportementales, d'auto-évaluation et électrophysiologiques répondaient aux critères d'inclusion et d'exclusion. Bien que leur qualité scientifique générale soit faible ou très faible, les résultats de la revue systématique appuient l'hypothèse qu'un effet d'acclimatation est présent, tel que documenté par les trois types de mesures. Pour la reconnaissance de la parole dans le bruit, l'amélioration varie entre 2 et 3 dB en termes de rapport signal sur bruit (RSB) sur une période minimale d'un mois. Cette étude met en évidence l'importance d'utiliser les AA après l'appareillage afin d'optimiser les bénéfices que celles-ci peuvent procurer.

L'objectif du deuxième article était de rapporter les résultats d'une étude longitudinale pour déterminer si l'acclimatation aux AA des personnes âgées peut être évaluée par leurs performances à des tâches de reconnaissance de la parole dans le bruit ainsi que par des mesures d'effort auditif. Trente-deux nouveaux utilisateurs d'AA et 15 utilisateurs expérimentés ont été évalués sur une période de 38 semaines en utilisant un paradigme de double tâche. Pour les nouveaux utilisateurs, les résultats ont révélé une amélioration significative de 2 dB RSB sur un test de reconnaissance de la parole dans le bruit après quatre semaines d'utilisation des AA, et aucune diminution de l'effort auditif, tel que mesuré par le coût proportionnel de la double tâche et par le temps de réponse à la tâche secondaire. Chez les utilisateurs expérimentés, les résultats n'ont dévoilé aucune amélioration de leur performance de reconnaissance de la parole dans le bruit suite à l'utilisation des AA.

En conclusion, les résultats confirment la présence d'un effet d'acclimatation tel qu'évalué par des mesures comportementales, d'auto-évaluation et électrophysiologiques suite à une utilisation régulière d'AA. Plus précisément, les nouveaux utilisateurs présentaient une amélioration cliniquement significative de 2 à 3 dB en termes de RSB après une utilisation régulière de leurs AA. Par conséquent, les nouveaux utilisateurs d'AA devraient être informés de cette possible amélioration au fil du temps, car cela pourrait les inciter à continuer de s'adapter à leurs AA plus longtemps avant de décider de les utiliser ou non.

Mots-clés : aides auditives, perte auditive, acclimatation, adaptation, personnes aînées, effort auditif

Abstract

Hearing aids (HAs) are the primary rehabilitation intervention recommended for older adults with hearing loss, as they provide a wide range of benefits. However, a large proportion of individuals who own HAs does not use or underuse them. The most recurring reason reported by non-HA users is their difficulty to understand conversations in noisy environments even when they use HAs. It is unclear if these individuals tried to use their HAs for an extended period of time before abandoning their use. If they gave up too soon after being fitted with their HAs they may not have benefited from an auditory adaptation to the new auditory stimulation, referred to as *auditory acclimatization*. The main objective of this thesis is to evaluate the contribution of HA experience on auditory acclimatization.

The first study aimed to determine, by means of a systematic review, if an acclimatization effect occurs after HA use and if so, to establish the magnitude and time-course of this effect. Fourteen articles that assessed acclimatization through behavioural, self-reported and physiological outcomes met the inclusion and the exclusion criteria. Although their general scientific quality was low or very low, the results of systematic review support the existence of an acclimatization effect as calculated by all three types of outcome measures. For speech-recognition-in-noise performance, improvement ranged from 2 to 3 dB in signal-to-noise ratio (SNR) over a minimum period of 1-month. This study highlights the importance of using the HAs on a regular basis after being fitted with HAs.

The goal of the second study was to conduct a longitudinal investigation in order to determine whether acclimatization to HAs by older adults can be assessed data obtained on a speech-recognition-in-noise task and by measures of listening effort. Thirty-two new HA users and 15 experienced HA users were tested over a 38-week period using a dual-task paradigm. For new HA users, the results showed a significant improvement of 2 dB SNR on a speech-recognition-in-noise task after 4 weeks of using the HAs post fitting. Based on the proportional dual-task cost data and by the response time measures recorded on the secondary task. No improvement of speech perception performance in noise was observed for the experienced HA users.

The general findings from this thesis support the presence of an acclimatization effect as measured by behavioural, self-reported and physiological measures following regular HA use. Specifically, new HA users show a clinically significant change of 2 and 3 dB SNR on speech-recognition-in noise tasks following their initial fitting. Therefore, new HA users should be informed of the possible improvement in speech recognition over time, as it could entice them to pursue the use of their HAs for a longer period of time before deciding to abandon them.

Keywords: hearing aids, hearing loss, acclimatization, adaptation, older adults, speech in noise, listening effort, dual-task paradigm

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List of acronyms

APHAB: Abbreviated Profile of Hearing Aid Benefit

ABR: Auditory brain response

CI: Cognitive impairment

DM: Directional microphone

DSST: Digit Symbol Substitution Test

FFR: Frequency-Following Response

FUEL: Framework for Understanding Effortful Listening

HHIE: Hearing Handicap Inventory for the Elderly

HL: Hearing loss

HA: Hearing aid

NRA: Noise reduction algorithm

OA: Older adult

OM: Omnidirectional microphone

SNR: Signal-to-noise ratio

SRM: Self-regulatory model

SSQ: Speech, Spatial and Qualities of Hearing Scale

RST: Reading Span Test

WDRC: Wide dynamic range compression

À ma famille, mon mari et notre future addition à la famille

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Chapter 1- Introduction

Age-related hearing loss (HL) is highly prevalent among older adults (OAs) and has many negative impacts that far exceed communication. HL may also influence psychosocial aspects, such as social isolation, loneliness and depression. More recently, HL has been identified as a risk factor for cognitive decline.

The hearing aid (HA) is the most prevalent intervention tool used when providing audiological rehabilitation services (Barker, Mackenzie, Elliott, Jones, & de Lusignan, 2014). It can improve communication, mitigate psychosocial factors such as depression, and it can potentially reduce the risk of cognitive decline (Chisolm et al., 2007; Dawes, Emsley, et al., 2015). Moreover, in recent years, the benefits provided by HAs have greatly improved with the advance of technology (Brons, Houben, & Dreschler, 2014). One might think that when an individual has a HL, the solution is simple: that person will use one or two HAs and all their problems will disappear. However, only a small proportion of individuals who would benefit from auditory amplification actually own HAs. Of the ones who do own HAs, a large proportion don't use them and/or aren't satisfied with them. The main reason why individuals decide not to use their HAs is the absence of, or low perceived benefit provided by, these devices, especially when they are used in a background noise environment.

It is generally accepted that new HA users need a certain period of time to adapt to their HAs in order to fully benefit from the amplification they provide. This auditory adaptation is referred to as *acclimatization*. It is important for individuals with HL to know that when they receive their HAs, it will take some time to adjust to them. That way, they will not get discouraged by the limited performance of the HAs and they will continue to adapt to the "new" amplified sound they perceive through their HAs. At the present time, little is known about the process of acclimatizing to HAs.

In this thesis, we explore the current knowledge concerning HA acclimatization by means of a systematic review. In addition, the results of a longitudinal experiment conducted to characterize the time course of acclimatization, as well as the magnitude of the acclimatization effect, are presented.

General introduction of age-related hearing loss

HL is a widespread and documented chronic disability among OAs. According to the World Health Organization (2018), 5% of the population has a disabling hearing impairment. This statistic increases to 33% when only individuals who are 65 years of age or older are considered. Age-related HL, also known as *presbycusis*, is influenced both by genetic and environmental factors, such as exposure to noise and ototoxic agents (Ruan, Ma, Zhang, & Yu, 2014). Presbycusis affects the outer hair cells and usually results in a symmetrical and bilateral HL, typically in the high frequencies (Lee, 2013). The consequences of HL are numerous and include difficulty understanding speech, especially in constraining environments (noise, reverberation, second language, etc.; Arlinger, 2003). To understand speech, its acoustic properties have to be audible. Audiological rehabilitation is defined as a treatment, or a combination of treatments, used to improve communication and reduce the perceived handicap of hearing impaired individuals (Kricos, 2000). For most individuals with HL, HAs are the main intervention tool for rehabilitation (Barker et al., 2014).

Normal aging has a physiological effect on the peripheral and central auditory pathways. Other than age, noise exposure, ototoxic agents and otological disorders can add to the damage (Gates & Mills, 2005). Because isolating the specific source of presbycusis is impossible, the typical contribution of age on the peripheral auditory system is a cumulative damage that occurs at the level of the outer hair cells of the cochlea. In addition, there is recent evidence that presbycusis, combined with an age-related cognitive decline, can contribute to a change in the central auditory system (Humes et al., 2012).

As proposed by the Working group on Speech Understanding and Aging of the Committee on Hearing and Bioacoustics and Biomechanics of the US National Research Council, the effect of progressive decline of hearing sensitivity on speech perception is two-fold (CHABA, 1988). First, age-related HL is typically characterized by a decrease in speech clarity because of the deterioration of hearing detection thresholds at high frequencies. Consequently, some parts of speech, especially consonants, become inaudible (Felipe, 2019). Second, difficulty understanding speech at suprathreshold levels is most common in the presence of background noise (CHABA, 1988). A combination of three hypotheses are proposed to explain these difficulties. The first hypothesis is the peripheral auditory hypothesis, which states that the difficulties are primarily attributable to the sensorineural HL and cochlear pathology that is common among OAs. Hence, the damaged peripheral auditory system can't separate background noise from the target speech as well as an auditory system in good health. The second hypothesis is the central-auditory hypothesis, which posits that age-related, modality-specific changes in the central auditory pathway from the lower brainstem through auditory centres of the cortex contribute to the communication difficulties. The modification in the central neural activity may lead to the difficulty to isolate speech from background noise. The third hypothesis is the cognitive hypothesis, which suggests that age-related decline in general cognitive functions, such as memory, attention, and speed of processing, is also at fault for communication constraints. It is noteworthy that the working group recognized that it was possible to have various combinations of these factors at work in a given individual (CHABA, 1988).

In the current chapter, the effects of age-related HL on speech understanding, on psychosocial outcomes and on cognitive decline are discussed.

Consequences of hearing loss on speech recognition

Speech understanding is a complex phenomenon that involves the peripheral auditory system, central auditory system and cognitive processes (Humes et al., 1994; Pichora-Fuller & Singh, 2006). Kiessling et al. (2003) identified four essential processes to define auditory functioning: (a) hearing, (b) listening, (c), comprehending, and (d) communicating. The Committee on Hearing and Bioacoustics and Biomechanics of the US National Research Council (CHABA, 1988) concluded that there are three age-related declines that can alter auditory functioning at different processing levels: the peripheral auditory system, the central auditory system and cognitive abilities. For effective communication, sound needs to be audible.

Consequently, OAs need to have normal hearing sensitivity or have amplified signals delivered to the peripheral and central auditory systems (Desjardins & Doherty, 2013). OAs must also have the cognitive abilities to select the sound, use their working memory to store the information, use their linguistic knowledge to decipher the information and generate a response. The interaction among those possible sources of decline is a complicating factor since they are highly correlated (Schneider, Daneman, & Pichora-Fuller, 2002). When OAs are in a degraded listening condition (e.g., reverberation or background noise), the task of understanding speech is cognitively more taxing (Anderson Gosselin & Gagne, 2011; Desjardins & Doherty, 2013). In a realistic context, rarely will speech be transmitted in a completely quiet environment, which is why difficulty with speech understanding in noise is the principal complaint reported by OAs with HL (Helfer & Freyman, 2008; Plomp, 1978).

According to the proposed Framework for Understanding Effortful Listening (FUEL) from the Fifth Eriksholm Workshop on “Hearing Impairment and Cognitive Energy”, speech perception relies on much more than just audibility and loudness (Pichora-Fuller et al., 2016). Based on Kahneman’s (1973) model, the FUEL explains the relationship between cognitive demands and the supply of cognitive capacity, while also taking in consideration motivation, adaptive gain control, optimal performance, fatigue and pleasure.

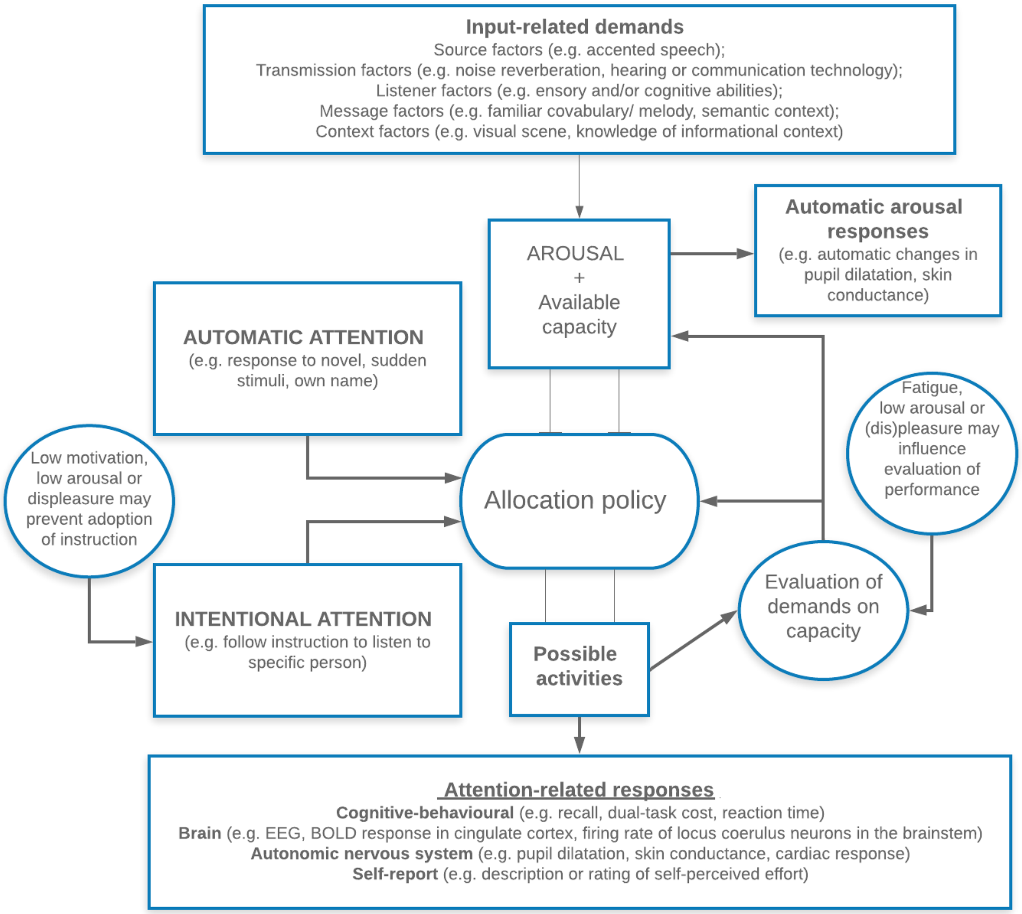


Figure 0.1. FUEL model adapted from Kahman's (1973) and Pichora-Fuller et al. (2016).

First, the model takes into account the characteristics of the initial message such as background noise, reverberation, accented speech, visual cues, etc. The available capacity will fluctuate according to the automatic level of arousal capacity and the allocation policy. According to Kahneman (1973) and Pichora-Fuller et al. (2016), the allocation policy is influenced by four factors: (a) involuntary or automatic attention, (b) intentional attention, (c) evaluation of demands, and (d) effect of arousal. In relation to listening effort, the allocation policy is also dependent on the executive functions and the available resources. This framework also includes miscellaneous factors such as fatigue, momentary intention and motivation that can influence the allocation policy and available capacity. Therefore, the ability to understand a message is influenced by many factors other than the characteristics of the message, the integrity of the auditory system and cognitive abilities. It is also influenced by automatic attention, the intention to understand the message, fatigue, the evaluation of demands, which can regulate motivation, and much more.

Working memory capacity has been established as playing an important role in speech understanding under difficult auditory environments such as background noise (Ronnberg et al., 2013). Ronnberg et al. (2013) proposed the Ease of Language Understanding model which stipulates that when the auditory signal is distorted or is not optimal, the listener's working memory will be called upon to assist in processing the signal into a meaningful message. There is evidence that there is a relationship between working memory capacity and performance on speech perception tasks, including when HAs are employed. A comprehensive review on this topic was provided by Souza, Arehart, and Neher (2015).

Another cognitive ability often associated with speech perception in noise is speed of cognitive processing (Brebion, 2001; Vaughan, Storzbach, & Furukawa, 2006; Wingfield, Lindfield, & Goodglass, 2000). Lunner (2003) found a significant correlation between verbal information processing speed, as measured by a rhyme judgment test, and speech-recognition-in-noise performances. Desjardins and Doherty (2013) reported that individuals with better speed of processing abilities as measured by the Digit Symbol Substitution Test (DSST), a test commonly used to measure speed of processing, performed significantly better on a speech-recognition-in-noise task than individuals with poorer speed of processing.

Consequences of hearing loss on listening effort

Listening effort is defined by "the amount of processing resources allocated to a specific auditory task, when the task demands are high and when the listener strives to reach a high-level of performance on the listening task" (Gagné, Besser, & Lemke, 2017, p. 1).

Listening effort has been measured by a wide range of techniques, including behavioural outcome, self-reported measures, and physiological recordings (McGarrigle et al., 2014). A closed-set response format is generally used to measure self-reported listening effort in questionnaires or rating scales. Two categories of behavioural measures have been proposed: the single-task paradigm and the multi-task paradigm. In the single-task paradigm, the experimental procedure consists of asking the participant to respond, verbally or tactilely, to an auditory stimulus. Although the relationship remains unclear, the speed of correct answers is typically believed to reflect the listening effort expended by the listener (McGarrigle et al., 2014). The multi-task paradigm, such as the dual-task paradigm, relies on the theory of attention allocation (Styles, 2006) which, when applied to hearing sciences, suggests that the more cognitive resources are required to understand speech, the less cognitive resources are available to perform a second simultaneous task. Although there is a great variability in experimental paradigms, the dual-task paradigm has shown good validity in previous studies (Desjardins & Doherty, 2013; Gagné et al., 2017; Gosselin & Gagne, 2011; Picou, Gordon, & Ricketts, 2016). Self-reported measures are a quick and easy way to evaluate the perceived listening effort. However, there has often been a lack of correlation between behaviourally measured listening effort and self-perceived listening effort (Anderson Gosselin & Gagne, 2011; Fraser, Gagne, Alepins, & Dubois, 2010; Larsby, Hallgren, Lyxell, & Arlinger, 2005). Larsby et al. (2005) suggest that individuals may perceive effort levels differently. Another explanation would be that the subjective measure of listening effort would reflect different aspects of listening effort rather than the availability or demand for processing resources (Anderson Gosselin & Gagne, 2011; Wickens, 1992; Zekveld, Kramer, & Festen, 2010). Finally, listening effort has previously been measured through physiological measures such as functional magnetic resonance imaging, electroencephalography, pupillometry and skin conductance. The most reliable and validated physiological method has been pupillometry. The fluctuation in pupil size, in a well-controlled experimental setting, can accurately reflect listening effort (McGarrigle et al., 2014; Zekveld & Kramer, 2014).

It is well recognized that individuals with HL will expend more listening effort than normal-hearing individuals when processing speech (Desjardins & Doherty, 2013; Tun, McCoy, & Wingfield, 2009; Xia, Nooraei, Kalluri, & Edwards, 2015). These individuals will often need a higher degree of concentration, which will lead to more fatigue at the end of a sustained conversation in everyday life (Kramer, Kapteyn, & Houtgast, 2006). Even if, in some situations, individuals with

HL can perform at the same level in a speech-perception-in-noise task as their normal-hearing counterparts, they will find the task considerably more taxing.

Adding to HL, aging is also associated with increased listening effort required to understand speech in noise. Gosselin and Gagne (2011) investigated self-reported listening effort and objective listening effort between young adults and OAs with normal hearing. Although no difference between groups was found for self-reported listening effort, results indicated that significantly more listening effort was deployed by OAs compared to young adults as measured by a dual-task paradigm.

Beyond age and HL, in view of the fact that cognitive function such as working memory capacity is allocated for speech understanding when the input is degraded (Ronnberg et al., 2013), it is reasonable to assume that better cognitive function may reduce the amount of expended listening effort required to successfully perform an auditory task in such an environment. Picou, Ricketts, and Hornsby (2011) evaluated the subjective and objective listening effort required for adults with normal hearing to understand speech in noise in an audio-only condition, and in an auditory-visual condition. Working memory was evaluated using the Automated Operation Span Task (AOSPAN; Unsworth, Heitz, Schrock, & Engle, 2005). Results confirmed that individuals with better working memory expend less listening effort to understand speech in an auditory-visual condition.

The challenge of sustaining high demands of listening effort in adverse listening conditions can lead to mental distress and chronic fatigue (Hetu, Riverin, Lalande, Getty, & St-Cyr, 1988), a dwindling of energy, increased sick leave from work due to stress (Kramer et al., 2006) and reduced quality of life (Strawbridge, Wallhagen, Shema, & Kaplan, 2000).

Psychosocial consequences of hearing loss

For people with hearing loss

Uncorrected HL can lead to a decrease of general well-being and quality of life (Seniors Research Group, 1999). More specifically, HL is associated with depression, loneliness, altered self-esteem and diminished functional status (Chen, 1994; Wallhagen, Strawbridge, & Kaplan, 1996). A longitudinal study by Strawbridge et al. (2000) analyzed the impact of hearing impairment on psychosocial functioning for 2,461 participants from 50 to 102 years of age over a 1-year period. Depression was measured using the DSM-III-R (American Psychiatric Association, 1987). Data of self-reported mental health was analyzed for two groups of participants: those with “a little HL” and those with “moderate HL or more”. Results revealed a depression odd ratio of 2.05 for individuals with at least a moderate HL. This indicates that individuals with a moderate HL or greater are twice as likely to experience depression than individuals with a mild or no HL.

The severity of HL has also been found to influence the level of psychosocial consequences. Nachtegaal, Festen, and Kramer (2011) found that a reduced hearing ability is associated with more severe psychosocial health consequences such as distress, depression and loneliness. Tambs (2004) found that, on average, mental health declined by 0.1 standard deviation (SD) for each 10 dB of HL. Moreover, the correlation between HL and psychosocial consequences is modulated by age. A longitudinal study by Tambs (2004) found that, compared to OAs, younger and middle-aged adults indicated having higher levels of anxiety and depression, lower self-esteem and a decrease of subjective well-being. The author suggests that OAs with HL may accept their HL more than younger adults, since it is expected for their age. Incidentally, it is possible that work-related disability contributes to the higher levels of mental distress in younger adults (Tambs, 2004).

For the communication partners

Communication partners (CPs) are the people with whom the individual with HL communicates on a regular basis. The opinions and behaviours of CPs are important for an individual’s psychosocial well-being, because it may influence the willingness of the person with HL to seek and adhere to audiological rehabilitation (Barker, Leighton, & Ferguson, 2017). CPs can be a spouse, a partner, close family members, friends or caregivers (Kamil & Lin, 2015). Previous studies have identified the social pressure exerted from friends and family members as the main reason why hearing-impaired individuals seek help and treatment (Duijvestijn et al., 2003; Mahoney, Stephens, & Cadge, 1996).

When communication between a person with HL and their CP is difficult, CPs can experience frustration and increased stress, which can result in a relationship deterioration (Savundranayagam, Hummert, & Montgomery, 2005). When miscommunication frequently occurs between two spouses, the CP may label the individual with HL as not involved or confused (Wallhagen, 2010). Due to a spouse's HL, the CP may also experience various negative physical, mental and psychosocial effects.

A systematic review was conducted, where the authors reviewed 24 studies that investigated the effect of a person's HL on CPs (Kamil & Lin, 2015). The outcome measures included quality of life, mental and emotional health, social life, relationship satisfaction and communication for the CP. The outcomes retained for the review were measured with qualitative interviews, established scales and/or ad hoc questionnaires in 18 studies. Sixteen out of the 18 studies found a significant decrease in quality of life among CPs (e.g., Hallam, Ashton, Sherbourne, & Gailey, 2008; Kelly & Atcherson, 2011; Scarinci, Worrall, & Hickson, 2012). Additionally, the decrease in social activities imposed by the individual's HL can have an indirect consequence on the spouse's level of social functioning (Knutson, Johnson, & Murray, 2006; Lormore & Stephens, 1994; Scarinci, Worrall, & Hickson, 2008; Wallhagen, Strawbridge, Shema, & Kaplan, 2004). Furthermore, the stress brought on by the communication difficulties led to lower relationship satisfaction (Anderson & Noble, 2005; Brooks, Hallam, & Mellor, 2001; Hallam et al., 2008; Knutson et al., 2006; Lormore & Stephens, 1994; Scarinci et al., 2008; Stephens, France, & Lormore, 1995).

However, improvement in quality of life is observed when HAs are used regularly by the person with HL (Brooks et al., 2001; Hickson, Worrall, & Scarinci, 2006; Stark & Hickson, 2004). Hence, understanding the impacts of an individual's HL on the spouse, family members and friends highlights the need for help-seeking and treatment adherence.

Consequences of hearing loss on cognitive decline

Cognitive impairment (CI) is defined by self-reported and/or objectively measured problems with memory, speech or decision-making, while basic activities of daily living are preserved (Portet et al., 2006). The severity of CI ranges from mild to severe. CI usually occurs between the stages of normal aging and dementia (e.g., Alzheimer’s, vascular dementia and dementia with Lewy bodies). The main difference between CI and dementia is that in dementia, more than one cognitive domain is involved and substantial interference with daily life is observed (Knopman & Petersen, 2014). Unfortunately, many individuals with CI present an Alzheimer’s disease biomarker (Amariglio et al., 2012; Meiberth et al., 2015; Spulber et al., 2012) and a large proportion of these individuals will eventually develop dementia. The annual conversion rate from mild CI to dementia is approximately 9.6% (Mitchell & Shiri-Feshki, 2009). This means that within 10 years after the CI is diagnosed, 96% of the surviving individuals with mild CI will have developed some kind of dementia.

Using a case-control design, the investigation reported by Uhlmann et al. (1989) was one of the earlier studies to reveal that HL is independently associated with CI and dementia. One hundred participants with Alzheimer’s disease and 100 cognitively normal age-matched participants took part in this study. Results showed that participants with Alzheimer’s disease were twice as likely to have a HL of 30 dB or greater than their cognitively normal counterparts. Moreover, in both groups (nondemented and demented), HL was significantly associated with the severity of cognitive dysfunction as measured by the Mini-Mental State Examination (MMSE).

The study by Lin, Ferrucci, et al. (2011) was the first longitudinal investigation to use objective measures to confirm that HL is independently associated with cognitive decline. Authors concluded that individuals with HL have significantly poorer memory and executive functions than their normal-hearing counterparts (Lin, Ferrucci, et al., 2011).

Knowing that a large proportion of people with CI develop some type of dementia, Lin, Metter, et al. (2011) investigated the relationship between HL and dementia. As expected, HL is correlated with dementia. The risk ratio of developing dementia increases as the severity of the HL increases.

It is well recognized that HL is associated with increased cognitive load, changes in brain structure, decreased social engagement and depression (Lin & Albert, 2014). Lin et al. (2014) found a significant 30-40% increased rate of brain atrophy of the whole brain and of the right temporal lobe among people with HL. As HL affects the ease of understanding, the cognitive resources needed to process the degraded auditory signal increase, at the expense of other cognitive processes such as working memory (Campbell & Sharma, 2013).

Baltes and Lindenberger (1997) proposed four hypotheses providing possible explanations for the mechanisms involved in cognitive decline related to HL. First, the common cause hypothesis proposes that HL and cognitive decline are symptoms of a widespread neural degeneration. However, this theory is inconsistent with previous research, which revealed that HL is independently associated with cognitive decline. Second, the cognitive load on perception hypothesis stipulates that perceptual decline is a consequence of the increased cognitive load brought on by cognitive decline. This theory is inconsistent with evidence that linguistic knowledge and the ability to use this knowledge to compensate for auditory deficits are well preserved in normal aging (Wingfield & Tun, 2001). The third hypothesis presented by Baltes and Lindenberger (1997) is the deprivation hypothesis, which posits that long-term perceptual deprivation such as HL results in permanent cognitive decline. The proposed underlying mechanism is that the frequent miscommunication can lead to social isolation and absence of stimulation, which in turn can lead to cognitive decline (Fortunato et al., 2016). Finally, the information degradation hypothesis suggests that poorer cognitive performance is due to short-term impoverished perceptual input triggered by the HL. The deprivation hypothesis and the information degradation hypothesis are two supported theories. The deprivation hypothesis is validated by recent studies that have used a longitudinal design to provide evidence of causality (Lin, Ferrucci, et al., 2011). Likewise, although more research is needed, results from recent studies lean towards confirming that the regular use of HAs decreases risk ratio of cognitive decline, which is in line with the information degradation hypothesis (Dawes, Emsley, et al., 2015).

Chapter 2- Hearing aids

The primary aim of HAs is to restore audibility by increasing the level of the input signal in frequency regions where the listener's HL affects audibility.

Many investigators have demonstrated the benefits of amplification on quality of life (Mulrow, Tuley, & Aguilar, 1992; Seniors Research Group, 1999), on speech perception in a quiet environment and in noise (Bentler, 2005; Valente, Fabry, & Potts, 1995), and on cognition (Castiglione et al., 2016; Dawes, Emsley, et al., 2015; Silva, Silva, & Aurelio, 2013). However, it is understood that HAs do not restore normal speech perception, especially in difficult listening environments (Lesica, 2018). Consequently, even with advanced technological improvements incorporated into HAs, OAs with HL may still have difficulty understanding speech under difficult listening conditions.

In this chapter, topics such as recent HA technologies, benefits and limits of HAs, and auditory acclimatization to HAs are covered. It is noteworthy that only digital technologies are considered because analog circuits are no longer available commercially.

Hearing aid technologies

In recent years, advances in HA technology have improved greatly. New technologies such as wide dynamic range compression (WDRC), directional microphones (DMs) and noise reduction algorithms (NRAs) were incorporated into HAs to improve the performances of HA users in tasks involving understanding speech in difficult listening situations (Lunner, Rudner, & Ronnberg, 2009).

Multichannel wide dynamic range compression

Individuals with HL have difficulty perceiving soft sounds, but also experience discomfort when the signal is presented at high levels (Dillon, 1996). This means that the range of detectable sound levels, typically referred to as the *dynamic range*, is reduced. The purpose of the WDRC is to compress the range of levels that are detectable by an individual with normal hearing into the dynamic range of the person with HL. The algorithm will apply a greater amount of gain to soft level sounds and the gain applied will be reduced as the intensity level of input sounds increases. Based on the profile of HL, the multichannel WDRC system applies different level-dependent gain ratios in different frequency bands. The reasoning behind applying WDRC is mostly to improve audibility and avoid discomfort, as well as to normalize loudness.

WDRC is characterized by several parameters, which sometimes can be modulated by the hearing health professional, including (a) the number of compression channels, (b) the compression threshold or knee point for compression activation, (c) the magnitude of gain reduction, referred to as the *compression ratio*, and (d) the speed with which the increase or decrease of input level is activated (attack and release time).

Evidence from previous studies support the benefits provided by WDRC on speech quality. A review by Souza (2002) notes that patients generally preferred fewer processing channels, reduced compression ratios and slower time constants. Despite the general improvement of speech quality observed when small compression ratios are used, excessive compression ratios are associated with poorer sound quality (Rosengard, Payton, & Braida, 2005).

A limit of WDRC is seen when attack and release times are too short, given that it can cause excessive distortion, which can have deleterious effects on speech perception (Dillon, 2012). Conversely, if the attack time is too long, in the event of a loud input signal, the HA wearer may be disturbed by the loud sound before the compression can be activated (Dillon, 2012). A similar issue can happen with release time. If the release time is too long, the activated compression will reduce gain and the audibility might be affected (Dillon, 2012).

Benefits from fast acting and slow acting multichannel WDRC may be influenced by the wearer’s cognitive function. Results from Lunner and Sundewall-Thoren (2007) revealed that HA users with better working memory, as measured by the visual letter monitoring test, performed better on a speech-recognition-in-noise task with fast-acting compression. It also showed that participants with poorer cognitive function performed better with slow-acting compression. A more recent study, however, did not find that working memory, as assessed by the Reading Span Test (RST), modulated the correlation between speech intelligibility and WDRC release times (Reinhart & Souza, 2016). Although the evidence that there is an interaction between working memory and WDRC is mixed, two studies revealed an improvement in speech intelligibility when WDRC is activated (Lunner & Sundewall-Thoren, 2007; Reinhart & Souza, 2016).

Commercially available hearing aids systematically include WDRC because there is a consensus on the positive effect of multichannel WDRC on speech intelligibility in quiet. Conversely, no clear advantage has been observed for speech recognition in background noise (see review by Souza, 2002).

Directional microphones

While multichannel WDRC can significantly improve speech recognition in quiet, it may also have a detrimental effect in noisy environments because it can increase the level of background noise when soft signals are detected (Stone & Moore, 2008). The only HA technology that has been shown to improve SNR and increase speech-recognition-in-noise performance is the use of directional microphones (DM) (Picou, Aspell, & Ricketts, 2014; Valente et al., 1995). The main objective of DMs is to spatially separate different sound sources arriving from different incident angles and to label them as desirable or undesirable (Blauert, 2005).

The directionality of HAs can be achieved through two principles. Modern HAs typically include two omnidirectional microphones with one port each. The second option, more common in smaller in-the-ear HAs, is to have one omnidirectional microphone with two ports (Dillon, 2012). In both cases, the sound delay between the entry of the sound in one port and the entry in the second port allows the internal circuit to differentiate them.

The two parameters characterizing the polar plane of directionality are the port spacing and the internal transmission delay. According to the evaluated position of the sound source, the latter may be attenuated by the internal circuit or sustained. For example, in a HA with DMs programmed in a cardioid polar plot (as shown in Figure 2.1.), the input sound with a 180° incidence will be labeled as unwanted and will be attenuated by the internal circuit (Ricketts, 2001). In modern HAs, there are many different types of polar plots that can adapt automatically or be adjusted by the hearing health professional. The modern array of DMs is beyond the scope of this thesis and the interested reader is referred to Ricketts (2001).

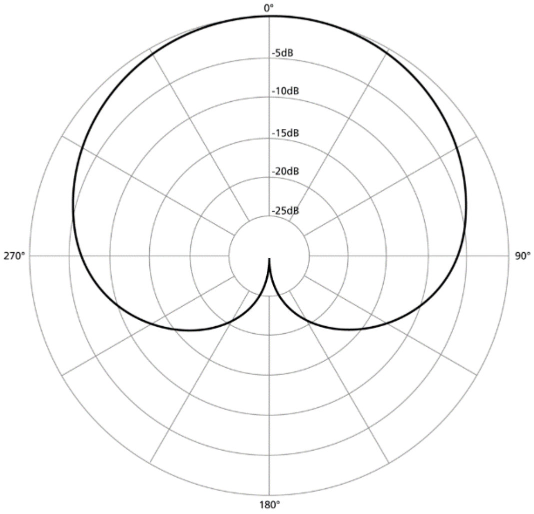


Figure 0.1. Cardioid polar plot of directional microphones.

The evidence supporting the enhancement of speech intelligibility provided by DMs is extensive (see reviews by Bentler [2005] and Ricketts [2001]). For example, Blamey, Fiket, and Steele (2006) investigated the speech-recognition-in-noise performances obtained when using adaptive DMs and omnidirectional microphones (OMs) under different noise conditions. Results confirmed that DMs yielded the best speech-perception-in-noise performances under all test conditions. One study, however, did report that the use of DMs did not have an effect on speech quality (Walden, Surr, Cord, Edwards, & Olson, 2000).

The benefits provided by DMs are influenced by many factors, including (a) the environment signal-to-noise ratios (SNRs), (b) the HL severity, and (c) the HA acoustic parameters (Ricketts, 2005). Walden et al. (2005) used a speech-recognition task in noise administered at different SNRs to compare DMs and OMs. The participants had moderate-to-severe HL (Walden et al., 2005). The results indicated that DMs offered better speech-recognition performances at all SNRs (-15 to +15 dB) and the greatest benefits were observed at SNRs of -3 and 0 dB (40-50% improvement). According to Ricketts, Henry, and Hornsby (2005), the benefits of DMs are limited when they are used by OAs with severe-to-profound HL. In addition, the directional advantage is reduced with an open-fit acoustic setting. For example, Magnusson, Claesson, Persson, and Tengstrand (2013) compared speech-recognition-in-noise performances for DMs in an open-fitting condition, and the same microphones in a closed earmold condition. Results revealed an improvement of 1.6 dB SNR in open-fitting conditions, compared to 4.4 dB SNR when the ear canal is occluded with an earmold. The authors concluded that, although reduced, the benefit of DMs is still significant in an open-fit HA.

The benefits of DMs measured in a laboratory setting are undeniable. However, in everyday life situations, some limitations of DMs are noticeable when the signal source is located behind the listener. An example would be having a conversation in an automobile. Communication in an automobile is difficult with HAs because there are many sources of high-level noise and visual cues are not always accessible. Wu, Stangl, Bentler, and Stanziola (2013) compared the speech perception abilities of 25 participants with HL in an automobile-like noise setting using DMs and OMs. Results showed a detrimental effect of DMs when speech was presented from the back and the side of the listener. Incidentally, DMs can have a detrimental effect on the ability to detect the source of the signal, generally referred to as *sound localization*. Many studies have shown that a HA user will have more difficulty localizing sounds that come from the back when the HAs are in directional mode (Keidser et al., 2006; Ricketts, Henry, & Gnewikow, 2003). The reduced localization ability can have a negative impact on the ability to understand a conversation in a noisy environment or among a group of people (Byrne & Noble, 1998).

Although DMs can interfere with sound localization and thus have a negative effect on speech understanding in specific situations, when the signal is located in front of the listener, DMs significantly improve speech understanding in noise.

Noise reduction algorithm

NRA is a complementary system to DMs in the event that desired and undesired signals are spatially close. Also, some commercially available HAs are too small (such as completely-in-the-canal HAs) to include two microphones or one microphone with two ports, which is required for a DM system. As for the DMs, the main objective of the NRA is to provide less gain for undesired noise compared to desired sound stimulus, in order to improve SNR and sound quality (Dillon, 2012). The specificities of the algorithm are different from one manufacturer to another and usually the algorithms are not available publicly. As a result, benefits of the NRA can vary widely from one manufacturing company to another. The digital NRA system originates from a modulation-based algorithm and typically applies a spectral subtraction approach (Dillon, 2012). This scheme assumes that signals that have greater modulations are more likely to be speech sounds and signals that have fewer modulations are more likely to be sources of noise. This analysis is done in multiple frequency bands, and the steady-state signals are cancelled or reduced (Dillon, 2012).

The evidence of improvements in speech-recognition tasks in noise provided by NRAs is mixed (Desjardins & Doherty, 2014; Magnusson et al., 2013; Oliveira, Lopes, & Alves, 2010; Walden et al., 2000). It seems that benefits on speech recognition in noise is mostly noticeable in a steady-state noise (Bentler & Chiou, 2006). The greatest benefits provided by NRAs are the improvements in comfort and sound quality reported by the users (Ricketts & Hornsby, 2005; Sarampalis, Kalluri, Edwards, & Hafter, 2009). Another benefit from NRAs is an alleviation of the listening effort expended to understand speech in noise. Using a dual-task paradigm, Desjardins and Doherty (2014) compared the listening effort expended to understand speech in noise with and without NRAs. While participants' speech-in-noise performance did not improve, the authors observed that NRAs had a significant positive effect on listening effort. Additionally, Sarampalis et al. (2009) noted that NRAs led to a reduction in listening effort in a speech-in-noise task when the SNR was low, which is more difficult.

In the experimental study presented in chapter 5, the hearing aids include WDRC, noise reduction algorithms and directional microphones. All commercially available hearing aids include WDRC and turning off this feature would be uncomfortable for the hearing aid wearer, especially for loud sounds. However, noise reduction algorithms and directional microphones are only activated when background noise is present. In recent hearing aid models, the activation of these features is automatic. Relative to the use of hearing aids with basic/minimal sound processing capabilities, the regular use of complex digital hearing aids (e.g. that include a NRA as well as directional microphones) could necessitate a longer adaptation period. This potential effect on acclimatization was investigated in the experimental study presented in chapter 5.

Benefits and limits of hearing aids

A systematic review by Ferguson et al. (2017) evaluated the self-reported benefits of HAs for individuals with mild-to-moderate HL. Results from the study revealed that HAs significantly improved speech perception abilities and quality of life. Moreover, benefits provided by HAs related to listening effort and cognitive functions are also discussed in this section. Some benefits are directly modified by the digital technology incorporated in the HAs and others are long-term effect of HA use. For an overview of the benefits of HA technologies on speech perception, sound quality and listening effort, see Table 2.1.

Speech perception

Although HAs can amplify sounds to improve speech recognition in quiet, annoyance of background noise and difficulty to understand speech in noise when using HAs are the most common complaints made by HA users (Kochkin, 2002). Many studies have shown significant improvements in speech-recognition performance in quiet provided by HA amplification. Larson et al. (2000) compared the benefits provided by three commonly used HA circuits in a double-blind design with a sample of 360 people with HL. Aided speech recognition in quiet was assessed with a monosyllabic word-recognition test using the NU-6 lists (Wilson, 1993), while speech recognition in noise was evaluated with the Connected Speech Test (CST: Cox, Alexander, & Gilmore, 1987) at three different SNRs (-3, 0 and 3 dB). Results from this study revealed that speech recognition in quiet and in noise was improved by all three types of HAs. While some authors agree that HAs can improve speech-recognition performances in noise (Healy, Yoho, Wang, & Wang, 2013; Yund & Buckles, 1995), many investigators failed to show any improvement on speech understanding tasks under difficult listening conditions (Chung, 2007; Dahlquist, Lutman, Wood, & Leijon, 2005; Ricketts, 2001).

The benefits of amplification on speech recognition in noise can’t be predicted with 100% accuracy because it is influenced by many factors, such as (a) degree of HL, (b) cognition, (c) level and type of background noise, and (d) technology of HA. Flynn, Dowell, and Clark (1998) suggest that the primary predictor of aided speech perception in noise is severity of HL. Data provided by Lunner and Sundewall-Thoren (2007) suggest that, in relatively easy listening conditions, pure tone average can predict 30% of the variance in aided speech-recognition-in-noise performance, while cognitive abilities can predict 40% of the variance under more difficult and complex listening conditions. In accordance with previous studies, Rudner, Foo, Ronnberg, and Lunner (2009) found that working memory, as measured by the Reading Span Test, could also be a predictor of aided speech recognition in noise.

Concerning the effects of the level of background noise, it is clear that, as the level of noise increases, it becomes more detrimental to speech understanding performances. Moreover, modulated background noise, allowing attenuation of noise between words, is preferred by HA wearers compared to steady noise (Dean & McDermott, 2000). In addition, the influence of the type of background noise on speech-recognition-in-noise performance is modulated by cognitive abilities (Lunner & Sundewall-Thoren, 2007).

As seen in the previous section on HA technologies, aided speech perception in quiet and in noise is also strongly modulated by the technology incorporated in the HAs.

Listening effort

As presented in the first chapter of this thesis, listening effort is referred to as an increased allocation of attentional and cognitive resources when a task is deemed difficult by the listener. Hence, if the task becomes easier by reason of increased audibility, one might assume that HAs can reduce listening effort. Effectively, most studies confirm this assumption.

Hornsby (2013) investigated the subjective and objective effect of HA use on listening effort in 16 adults with HL. Listening effort was assessed through a dual-task paradigm using a word recognition in noise test as the primary task, and word recall and visual response time as the secondary task. Results of the study showed that participants' visual response times were shorter in the aided condition, which represents a reduction of listening effort. Furthermore, data from self-reported questionnaires on listening effort also indicated a reduction of listening effort associated with HA amplification. Using subjective ratings of perceived effort, Hallgren, Larsby, Lyxell, and Arlinger (2005) found that listening effort was significantly reduced for a speech-recognition test, but only when the task was administered in quiet. Picou et al. (2013) found that working memory significantly correlated with the reduction in listening effort provided by HA use.

Although most investigators agree that acoustic amplification provided by HAs can reduce listening effort, the amount of benefit is influenced by HA technology. NRAs have been shown to reduce listening effort of individuals with HL when listening to speech in noise (Desjardins & Doherty, 2014). Neher, Grimm, Hohmann, and Kollmeier (2014) used a dual-task paradigm to assess listening effort for a sentence recognition task administered in a background of cafeteria noise. The authors reported an attenuation in the amount of listening effort expended only when the NRA was set at “strong”. Additionally, although results from Wu et al. (2013) showed no benefits of HA use on listening effort in an automobile-like noise with OMs, when the HAs were set in a DM mode, listening effort significantly decreased. Consequently, NRAs and DMs can significantly influence listening effort.

It is generally agreed that HAs can reduce the listening effort required to perform a speech-in-noise task. However, in a recent systematic review, Ohlenforst et al. (2017) noted that the wide variety of study protocols and of study groups (age, severity of HL, types of HAs, etc.) used across studies makes it difficult to conclude convincingly that HAs reduce listening effort.

Quality of life

The benefits of HA use on quality of life are well recognized. Mulrow et al. (1992) defined quality of life as “a multidimensional concept encompassing social, affective, cognitive and physical domains” (p. 1403). Mulrow et al. (1992) conducted a longitudinal study with 192 elderly hearing-impaired veterans to evaluate long-term benefits of HA use on quality of life, using disease-specific and generic questionnaires. The disease-specific questionnaires included the Hearing Handicap Inventory for the Elderly (HHIE: Weinstein, Spitzer, & Ventry, 1986) and the Quantified Denver Scale of Communication Function (QDS: Alpiner, 1982). Generic questionnaires were the Short Portable Mental Status Questionnaire (SPMSQ: Pfeiffer, 1975) and the Geriatric Depression Scale (GDS: Yesavage et al., 1983). Results revealed that after 4 months of HA use, quality of life improved significantly, specifically in the social, emotional and communication areas, as best measured by the disease specific questionnaires (HHIE and QDS). Moreover, psychosocial benefits attributable to HA use were sustained after a 1-year period. No changes were observed for quality of life related to the cognitive domain. It is noteworthy that no control group of experienced HA users were included in this study (Mulrow et al., 1992).

Nkyekyer, Meyer, Pipingas, and Reed (2019) used the short form of the GDS to assess depression among 40 participants with HL at three different moments: at fitting, at 3- and at 6-month post-HA fitting. Results showed a significant reduction of depressive symptoms, with a large effect size (Cohen's *d* = 0.87) after HA use. It is worth mentioning that in addition to being fitted with HAs, participants in this study concurrently took part in an auditory training treatment program.

Mener, Betz, Genther, Chen, and Lin (2013) used a cohort of 1,029 participants from 70 to 79 years of age from the National Health and Nutrition Examination Survey (NHANES) to investigate the influence of HL and HA use on major depressive symptoms. Although no significant association was found between HL and major depressive symptoms, HA use was significantly associated with lower odds of developing them. This supports the hypothesis that the use of HAs can reduce psychological effects and improve quality of life.

A systematic review of health-related quality of life and HAs was conducted by Chisolm et al. (2007). Sixteen studies, including two randomized control trials, were included in this systematic review. When measured using disease-specific questionnaires (e.g., HHIE), investigators found that, for between-subject studies, the regular use of HAs had a significantly large positive effect on hearing-related quality of life (Cohen's *d* = 2.07, 95% CI = 0.51-3.63). Chisolm et al. (2007) concluded that HAs reduce psychological, social and emotional effects of HL. Furthermore, a more recent systematic review of the effect of HA use on hearing-related quality of life in adult patients with mild-to-moderate HL included five randomized control trials and came to the same conclusion (Ferguson et al., 2017). Additionally, Ferguson et al. (2017) found a significant effect of HAs on general health-related quality of life.

To identify specific daily life activities influenced by HA use, Stephens and Meredith (1991) asked 38 new HA users to fill out an open-ended questionnaire that required the participants to list the benefits and limits of their HAs. The activities most often listed by participants as showing benefits from using HAs were television, general conversation and hearing in church/chapel. The most prevalent drawback listed was background noise. Difficulty in group conversations and lack of clarity were the second and third most listed difficulty. Overall, participants reported that the benefits provided by the HAs in different everyday life activities improved their quality of life.

Consequently, there is strong evidence that the use of HAs successfully reduces psychosocial effects of HL and improves hearing-related quality of life.

Cognitive functions

The evidence of the impact of HA use on cognitive function is inconsistent and generally of limited scientific quality. In a cross-sectional analysis from the Baltimore Longitudinal Study of Aging (BLSA), investigators associated the severity of HL with mental status, memory and executive functions. However, they reported that when controlling for demographic factors, HA users had similar cognitive function as non-HA users (Lin, Ferrucci, et al., 2011). Consistent with this study, a more recent observational study including 666 participants, and adjusted for demographic data, concluded that HAs do not lead to long-term better cognitive functions (Dawes, Cruickshanks, et al., 2015).

Another study used a cross-sectional design with a subsample of the UK Biobank including 164,770 participants (Dawes, Emsley, et al., 2015). Data analysis controlled for social demographics, social isolation and depression. Results revealed a significant and direct positive effect of HA use on cognition. Concurring with the aforementioned study, data from Qian et al. (2016) confirmed that HA users had better cognitive performance than non-HA users with HL. Authors suggest that HAs be strongly recommended to OAs with HL in order to minimize or delay cognitive decline.

Thus far, no study has investigated the long-term positive impact of HA use on cognitive functions with a longitudinal repeated measures design. Although some studies seem to lean towards cognitive benefits from HA use, stronger evidence is needed in order to confirm that HAs can reduce the risk of cognitive decline.

If HAs do delay the onset of cognitive decline, the mechanisms underlying this outcome is unknown and require clarification. Because hearing aid use is positively correlated to cognition, independently of depression and social isolation, it is not compatible with the common cause hypothesis and the cognitive load on perception theory. Studies that associated HA use with better cognitive abilities support the deprivation hypothesis and the degraded information hypothesis discussed in Chapter 1. Hence, the use of hearing aids

Table 2.1. *Benefits and limits of digital hearing aid technologies*

Digital technology	Benefits	Limits
WDRC	↑ Speech quality ↑ Audibility ↑ Comfort ↑ Loudness normalization	↓ Speech quality (high CR) ↓ Speech quality (short attack/release time) = Speech recognition in noise
DM	↑ Speech recognition in noise ↓ Listening effort	↓ Speech recognition in 360° listening environment ↓ Sound localization
NRA	↑ Comfort in noise ↑ Sound quality ↑ Speech recognition in noise (steady-state noise) ↓ Listening effort	↓ or = Speech in noise (modulated noise)

Note. CR = compression ratio

Help-seeking and hearing aid adherence

The available literature indicates that HAs provide many benefits and are effective for improving speech perception (especially in quiet), quality of life and possibly cognitive function. However, individuals with HL wait on average ten years before seeking professional help (Davis, Smith, Ferguson, Stephens, & Gianopoulos, 2007). Meyer and Hickson (2012) noted that older age, poorer hearing thresholds, higher degree of activity limitations and support from a significant other are factors that can lead to shorter help-seeking delays.

Heffernan, Coulson, Henshaw, Barry, and Ferguson (2016) proposed to use the self-regulatory model (SRM) as a theoretical model to better understand the psychosocial impacts of HL. The SRM, which was initially proposed by Leventhal, Meyer, and Nerenz (1980), examined whether a health behaviour is related to the sensation of fear and the perception of a health threat. The model posits that cognitive and emotional representations can influence the coping process and, in the end, health outcomes. Heffernan et al. (2016) applied this model to explore the psychosocial experiences of adults with mild-to-moderate HL. The qualitative results showed that cognitive representations of HL and HAs were mostly detrimental to help-seeking and adherence to aural rehabilitation, given the stigmatization associated with acquired HL. Consequently, the decision to seek and adhere to auditory rehabilitation is not only influenced by health factors such as degree of HL and of perceived handicap, but also by the individual's positive or negative perception of the social acceptability and the expected outcomes of HAs (Heffernan et al., 2016).

Among those that do obtain HAs, a large proportion does not use or underuse them. Studies show that 5 to 25% of individuals with HL that own HAs don't wear them (see Table 2.2. for more details). A recent article by Simpson, Matthews, Cassarly, and Dubno (2019) reported that married individuals with a higher socio-economic status were more likely to be successful HA users. McCormack and Fortnum (2013) conducted a review exploring the reasons that explain why individuals don't use their HAs. Authors noted that the most common reasons were the ones related to low HA value and lack of comfort. The most prevalent factor leading towards low HA value is limited benefits in noisy situations. As per McCormack and Fortnum (2013), on average, 35% of non-HA users complained about this specific difficulty. It is unclear if the participants had tried to use their HAs on a regular basis for a few months to adapt to new auditory cues before giving up.

Table 2.2. *Hearing aid use in different countries*

Authors (year)	Country	Number of participants (Age [years])	Measurement	Hearing aid use (% of users)
Solheim & Hickson (2017)	Norway	181 (60 to 100)	Data-logging	< 30 minutes/day (16%)
Aazh et al. (2015)	UK	1,012 (17 to 105)	Self-reported	Never* (10%) < 1 hour/day (5%) 1 to 4 hours/day (13%) > 4 hours/day (71%)
Oberg et al. (2012)	Sweden	124 (> 85)	Self-reported	Never* (13%)
Hougaard & Ruf (2011)	France	Unknown	Self-reported	Never* (6%)
	Germany	Unknown	Self-reported	Never* (5%)
	UK	Unknown	Self-reported	Never (7%)
	USA	Unknown	Self-reported	Never (12%)
Hartley et al. (2010)	Australia	307 (49 to 99)	Self-reported	Never* (24%) 1 to 4 hours/day (23%) > 4 hours/day (37%)
Lapsakko et al. (2005)	Finland	601 (> 75)	Self-reported	Never* (25%)

Note. Hearing aids were not worn at all.

Auditory acclimatization to hearing aids

HA adherence is mostly influenced by the HA user's perceived benefits in noisy environments and background noise (McCormack & Fortnum, 2013). If new HA users were aware of the potential improvement in speech understanding in noisy environments over time, it may entice them to persist trying to adapt to their HAs over a longer period of time before choosing to abandon their use.

Over time, new hearing aid users may adapt to their hearing aids and learn how to use the new auditory cues. Arlinger et al. (1996) proposed the term acclimatization to describe this process. This acclimatization is defined as "a systematic change in auditory performance linked to a change in acoustic information which cannot be attributed to task, procedural or training effects" (Arlinger et al., 1996, p. 87S). Evidence of acclimatization following HA fitting is mixed. Some investigators did not report evidence of auditory acclimatization (Dawes, Munro, Kalluri, & Edwards, 2014b; Humes, Wilson, Barlow, & Garner, 2002; Saunders & Cienkowski, 1997; Taylor, 1993; Turner & Bentler, 1998) while others have measured a significant acclimatization effect (Cox & Alexander, 1992; Dawes & Munro, 2016; Gatehouse, 1992; Munro & Lutman, 2003; Wright & Gagné, 2020). Typically, when acclimatization is measured, effect size is small and there is a large interindividual variability, which could explain the inconsistent results reported in the research literature (Wright, Hotton, & Gagné, 2020).

The first objective of this thesis was to conduct a systematic review on acclimatization to HAs in an attempt to address two questions. The first research question was: Do previous studies confirm the presence of an acclimatization effect among adults with HL following bilateral fitting of HAs? The second question was: If so, what is the time-course and magnitude of the acclimatization effect? Results of the systematic review are presented in Chapter 4 and discussed in Chapters 4 and 6.

Although many investigators have used percent correct performance on speech-recognition scores to measure acclimatization to HAs, as far as it can be determined, no longitudinal studies have used measures of listening effort to investigate acclimatization. As previously mentioned, HAs have been shown to significantly reduce the listening effort expanded to understand speech in a noisy environment. Therefore, this thesis also sought to investigate if this reduction of listening effort is influenced by HA acclimatization.

Consequently, the second objective of this thesis was to conduct a longitudinal study to measure the effect of acclimatization to HAs by OAs through two outcome measures: (a) speech-recognition-in-noise performance and (b) listening effort expended to understand speech in noise. This study also investigated the magnitude and time-course of acclimatization and the impact of certain factors on the acclimatization effect, such as DMs, NRAs and cognitive abilities.

Chapter 3- Methodology

Systematic review

For the first objective of this thesis, the authors of the systematic review followed the Centre for Reviews and Dissemination's (CRD) guidance for undertaking reviews in health care (Centre for Reviews and Dissemination, 2008). The appraisal of scientific quality followed the framework proposed by the GRADE Handbook for grading the quality of evidence and the strength of recommendations (GRADE Working Group, 2013). The data collection and study selection were done by the first author (myself) and validated by the second author (MH). Successive rounds of verification were done by both authors until an inter-judge agreement of 90% was reached. For more details on the methodology used to conduct the systematic review, see "Methods" section of Chapter 4.

Longitudinal study

For the second objective, methodology was designed to avoid limits identified in previous studies investigating HA acclimatization. For example, a longitudinal design was chosen to substantiate the temporal relationship between performance on outcome measures and acclimatization to HAs. Incidentally, one eligibility criterion included in the study specified that all participants had to use their HAs for at least 6 hours per day, as determined by objective measures. This criterion assured that possible improvement of auditory performance could be attributed to HA use.

Participants

Participants were recruited from the bank of participants of the CRIUGM, the clinic of speech-language pathology and audiology of the University of Montreal, and from word of mouth. Experienced HA users continued using their own HAs throughout the experiment. At the first testing session, real-ear insertion gain (REIG) was conducted to ensure that NAL-NL2 prescription targets were reached. Gain modifications were applied to participants' HAs when needed. See Table 3.1. for information on HAs, years of HA experience and gain modification.

Table 3.1. *Hearing aid information for experienced hearing aid users*

Experienced HA users	HAs used in the study	Years of experience with HAs	Modification of gain at session 1
NM	Starkey 3 series i30	3	No gain modification
JB	Unitron Moxi Fit 800	8	No gain modification
PG	Oticon Alto Pro	5	Increased soft and moderate sounds (55 and 65 dB SPL) 5 dB SPL from 2 to 5 kHz in right ear. No gain modification in left HA.
RD	Unitron Moxi^2 Kiss 16	3	Increased soft sounds (55 dB SPL) 8 dB SPL from 2 to 3 kHz in left HA. No gain modification in right HA.
GV	Unitron Moxi Kiss 800	1	No gain modification
RC	Siemens Pure 3mi	1	Changed closed domes for open domes since patient had occlusion effect in own voice. Recalculated NAL-NL2 with new acoustic parameters.
LB	Phonak Audéo V-50 312T	1.5	No gain modification
MD	Unitron Moxi Kiss 700	1.5	No gain modification
MA	Siemens Pure CE 123	3	No gain modification

LS	Phonak Audéo SMART III	15	No gain modification
SL	Unitron Moxi Fit 800	3	No gain modification
LC	Phonak Audéo SMART III	6	No gain modification
SG	Unitron Moxi Fit 800	1	No gain modification
RV	Unitron Moxi 12	4	No gain modification
RL	Unitron Moxi Fit 700	1	No gain modification

Test material

French version of the HHIE

The English version of the HHIE was translated into French because no previously translated version was available at the time of the experiment (see Appendix II).

Montreal Cognitive Assessment

The Montreal Cognitive Assessment (MoCA; Nasreddine et al., 2005) was administered to each participant. The test is administered using live voice. A personal amplification system (a pocket talker) was used when necessary. This brief cognitive screening instrument has been previously validated (Freitas, Prieto, Simoes, & Santana, 2015; Gauthier et al., 2011) to measure global cognitive function. The MoCA is a 30-point test administered in 10 minutes.

First, there is a 5-point recall task involving two learning trials of five nouns and recall after approximately 5 minutes. The visuospatial task involves drawing a clock (3 points) and a three-dimension cube copy (1 point). An alternation task adapted from the

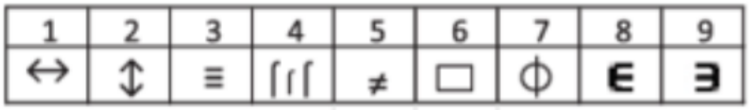
Trail Making B task (1 point), a phonemic fluency task (1 point) and a two-item verbal abstraction task (2 points) assess multiple aspects of executive function.

Executive functions such as attention, concentration and working memory are assessed by a sustained attention task which consists of target detection using tapping (1 point), by a serial subtraction task (3 points) and by a forward and a backward digit recall tasks (2 points). Language is evaluated using an identification task (a lion, a camel and a rhinoceros; 3 points), a repetition of two syntactically complex sentences (2 points) and a fluency task (participants must name a maximum number of words starting with the letter F; 1 point if they name more then 10 words).

Finally, orientation is assessed by asking time and place (6 points). This test was administered during the pre-session only and the results were considered only as part of an inclusion criteria. The participants had to obtain a minimum score of 26/30 in order to be included in the study.

Digit Symbol Substitution Test

The DSST, which is taken from the Wechsler Adult Intelligence Scale (Wechsler, 1997), consists of numbers that are symbol-coded. The participants are asked to use the code table to associate each number to the correct symbol using a pen and the sheet of paper displaying the code table and symbols legend (see Figure 3.1). On the same piece of paper, a row of double boxes is presented with numbers in the top boxes and empty boxes underneath. In the empty boxes, participants are instructed to associate the numbers with the correct symbol. The score is calculated according to how many numbers the participant correctly associated in 90 seconds.



1	2	3	4	5	6	7	8	9
↔	↕	≡	⌠⌠⌠	≠	□	ϕ	∈	∋

Figure 0.1. Digit Symbol Substitution Test code table.

Reading Span Test

The French version of the RST was used in this study (Desmettes, Hupet, Schelstraete, & Ven Der Linden, 1985). This test is composed of five lists of five blocks of sentences (see Annex III for the complete list of sentences). Participants are presented increasingly longer blocks of sentences on a computer screen (from two to six sentences per block). They are asked to read them out loud at their own pace without interruption. The participant reads one sentence and touches the screen monitor so that the next sentence is projected on the computer monitor. This procedure is followed until no more sentences are presented.

After reading all sentences from a block, the participant is asked to repeat the last word of each sentence without starting with the last sentence presented. There is no time limit for this task. If all the words in a block are repeated correctly, the next block is presented. The first test stimulus presented is a block of two sentences. If the participant correctly repeats the last words of each sentence, a block of three sentences is presented. This procedure is repeated up to a maximum of six sentences. If the participant does not repeat correctly all of the last words presented within a block, the test procedure is stopped. Then, the complete test procedure, starting with a block of two sentences, is initiated for a second time. The maximum score possible for one block of sentences is 20 points.

Three blocks are completed for each participant. Working memory capacity is defined as the number of words successfully recalled by the participant compared to the total number of possible points (60). Blocks of two and three sentences are used to familiarize the participants with the test procedures. The authors of the French adaptation of the RST recommend that only the first three lists be used, since there is a training effect with the fourth and fifth lists (Desmettes, 1995).

Dual-task description

A custom computer program (Leclab) and a GSI 61 audiometer were used to conduct the experiment. Audio files from Leclab (HINT sentences) were routed to channel one of the audiometer and speech-shaped noise was generated from channel two. The HINT sentences were routed to a loudspeaker (Realistic, Minimus-77) placed 1 metre in front of the participant and the speech-shaped noise came from another loudspeaker (Realistic, Minimus-77) placed 1 metre directly behind the participant. Free-field acoustic calibration was conducted before each testing session to ensure a consistent output of 65 dB SPL for the speech-shaped noise, and an initial output of 65 dB SPL for the HINT sentences.

For the dual-task paradigm, the Canadian French version of the HINT ($HINT_{FC}$: Vaillancourt et al., 2008) was used as the primary task and the tactile pattern-recognition task (TPRT) as the secondary task. The $HINT_{FC}$ is composed of two practice lists of 20 sentences and 12 lists of 20 sentences. In order to have a more precise measure of performance, original lists were merged together to create six double lists of 40 sentences. The presentation of $HINT_{FC}$ lists was counterbalanced for all participants.

The secondary task involved a TPRT in which participants had to identify the duration of three consecutive vibrations (i.e., short-short-long, short-long-long, etc.). Secondary tasks using a TPRT have been successfully used previously in experiments measuring listening effort (Gosselin & Gagne, 2011). The duration of the short pulse was 250 ms and the long vibration was 500 ms. The pulses were generated through a small oscillator (Radioear B-71) typically used for bone-conduction audiometry. The vibrations started 100 ms after the auditive stimuli of the primary task and there was an inter-stimulus interval of 100 ms. Participants were asked to use their dominant hand to perform the TPRT and they used the same hand for all testing sessions. They held the oscillator in the palm of their hand and placed their hand in a box containing sound attenuating foam.

Under the dual-task condition, the primary task and the secondary task were conducted concurrently. After each trial, participants were asked to repeat orally the sentence first, and then to identify with their free hand the tactile pattern on the touch screen monitor in front of them (ELO TouchSystems, ET1725L). The software recorded the accuracy and the response time of each answer.

Protocol

The complete test protocol was administered during nine test sessions: one pre-session and eight experimental test sessions. During the pre-session, participants were asked to read and sign the consent form (see Annex I). Subsequently, participants underwent a complete audiometric assessment, including otoscopy, immitancemetry, pure tone air and bone conduction audiometry and speech audiometry. Additionally, the MoCA, the DSST, the RST and the French version of the HHIE were administered. At the following test session, the first experimental test session, all new HA users received their HAs and REIG measures were conducted for all participants (new and experienced HA users). During the same test session and the following eight experimental test sessions, all participants performed the primary and secondary task separately and concurrently.

For a detailed overview of the experimental procedure, the reader is referred to section "Materials and methods" of Chapter 5.

Chapter 4- Acclimatization to hearing aids: systematic review

Systematic review on acclimatization to hearing aids

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Abstract

Purpose: The main objective was to conduct a systematic review to weigh the evidence regarding a possible acclimatization effect following hearing aid fitting. Additional objectives were to determine the time-course and magnitude of the acclimatization effect and to identify factors influencing acclimatization.

Method: Only longitudinal studies involving adult hearing aid users with no previous hearing aid experience were included. Categories of outcome measures were behavioural, self-reported and electrophysiological. Authors used a consensus approach to extract articles and to assess the scientific quality of outcome measures. Guidelines from The Centre for Reviews and Dissemination (CRD) and from the Grading of Recommendations, Assessment, Development and Evaluation (GRADE) were used for data collection, bias assessment and appraisal of level of evidence.

Results: Fourteen studies met the inclusion criteria. Because of study limitations, imprecision and inconsistency, the scientific quality of the studies was judged as being low or very low for almost all outcomes of interest. Results from all three categories of outcome measures support the evidence of an acclimatization effect. The time-course appears to be of at least one month and the magnitude, as measured by speech recognition in noise, ranges from changes of 2-3 dB SNR. The most important factor influencing acclimatization is hearing aid use.

Conclusion: An acclimatization period occurs after hearing aid fitting. New hearing aid users should be informed of this effect as it could entice them to persist trying to adapt to their hearing aids for a longer period before deciding whether or not to keep the aids.

Keywords: Hearing aids, Hearing loss, Adaptation, Physiological, Speech perception

Introduction

Description of the condition

Hearing loss (HL) is a widespread and documented chronic disability among older adults. According to the World Health Organization (2018), five percent of the population has a disabling hearing impairment. This prevalence increases to 33 percent for persons who are 65 years of age or older. The consequences of HL are numerous and include difficulty understanding speech, especially in constraining environments (noise, reverberation, second language, etc.) (Arlinger, 2003). Untreated HL can lead to an increased risk of cognitive decline (Lin et al., 2013), and to a decrease in general wellbeing and quality of life (National Council on the Aging, 1999).

Hearing aids (HAs) constitute the first audiological treatment option proposed to persons with HL (Barker, Mackenzie, Elliott, Jones, & de Lusignan, 2014). However, fewer than 1/3 of individuals with HL use HAs (National Council on the Aging, 1999), and these individuals wait 10 years on average before seeking help (Davis, Smith, Ferguson, Stephens, & Gianopoulos, 2007; Laplante-Levesque, Hickson, & Worrall, 2012; Simpson, Matthews, Cassarly, & Dubno, 2019). Over the last 30 years, advances in HA technology such as wide dynamic range compression, directional microphones and noise reduction algorithms have been incorporated into HAs in order to improve speech understanding and performances of HA users, especially under difficult listening conditions (Lunner, Rudner, & Ronnberg, 2009). Investigators have demonstrated the benefits of amplification on quality of life (Mulrow, Tuley, & Aguilar, 1992; Seniors Research Group, 1999), on speech perception in both quiet and noisy environments (Bentler, 2005; Valente, Fabry, & Potts, 1995), and on cognition (Castiglione et al., 2016; Dawes et al., 2015; Silva, Silva, & Aurelio, 2013). Notwithstanding the advantages provided by HAs, it is generally accepted that new HA users undergo an acclimatization period before they fully benefit from their use.

Acclimatization to HAs has been a topic of interest in the research literature. Gatehouse (1989) was the first to use the term acclimatization in a context of adaptation to new auditory cues following the use of HAs. According to the Report of the Eriksholm workshop on auditory deprivation and acclimatization, acclimatization is defined as "a systematic change in auditory performance linked to a change in acoustic information which cannot be attributed to task, procedural or training effects" (Arlinger et al., 1996, p.87S). Arlinger et al. (1996) stated that acclimatization is limited to speech identification abilities in silence and in noise as well as improvements on psychoacoustical tasks, including loudness adaptation.

The results of previous investigations of the acclimatization effect are mixed. While some investigators have failed to show evidence of an auditory acclimatization effect (Dawes, Munro, Kalluri, & Edwards, 2014; Humes, Wilson, Barlow, & Garner, 2002; Saunders & Cienkowski, 1997; Taylor, 1993; Turner & Bentler, 1998), others have reported an improvement on auditory tasks that have been attributed to HA acclimatization (Cox & Alexander, 1992; Dawes & Munro, 2016; Gatehouse, 1992; Munro & Lutman, 2003; Yund, Roup, Simon, & Bowman, 2006). Typically, when acclimatization is measured, the effect size is small and there is a large interindividual variability in the amount of acclimatization displayed across the participants. This could contribute to the inconsistencies in the results reported across the studies.

Palmer, Nelson, and Lindley (1998) identified factors that may account for some of the variability in auditory acclimatization observed in the literature. They include: (1) selection and adjustment of HA fitting parameters that may lead to differences in audibility, (2) HA use, (3) differences in signal processing algorithms, (4) age range and degree of HL of the participants, (5) test material used to measure acclimatization and (6) use of experimental procedures that fail to control for learning effects. The large variability in study design and methodology among studies complexifies this area of research and limits the generalizability of the results (Palmer, 1998).

Previously published reviews on acclimatization

The evidence in support of an acclimatization effect after HA fitting is mixed. While no previous systematic review on acclimatization has been published, nine scoping reviews were identified (Arlinger et al., 1996; Bentler, Holte, & Turner, 1999; Byrne & Dirks, 1996; Palmer et al., 1998; Ponton, 1996; Robinson & Summerfield, 1996; Thai-Van, Philibert, Veuillet, & Collet, 2009; Turner, Humes, Bentler, & Cox, 1996; Willott, 1996). Of those scoping reviews, all but one (Bentler et al., 1999) concluded that an acclimatization effect occurs after the initial HA fitting. However, there are large inter-subject variability and conflicting results across investigations. Three of the identified reviews are discussed below to illustrate the potential effects of different variables on acclimatization measures, to describe the non-invasive imaging techniques that could potentially be used to measure the physiological changes associated with auditory acclimatization, and to provide evidence that auditory acclimatization may be measured with non-speech stimuli (Byrne & Dirks, 1996; Ponton, 1996; Turner et al., 1996).

Turner et al. (1996) identified 10 articles, one PhD dissertation and one poster presentation on acclimatization. Of those, acclimatization to monaural amplification was reported in five of the articles and one PhD dissertation (Cox, Alexander, Taylor, & Gray, 1996; Gatehouse, 1992, 1993; Horwitz, 1995; Malinoff & Weinstein, 1989; Mulrow et al., 1992). Five studies included participants who used either monaural or bilateral amplification (Arkis & Burkey, 1994; Bentler, Niebuhr, Getta, & Anderson, 1993, 1993; Cox & Alexander, 1992; Taylor, 1993). The poster presentation (Humes et al., 1995) summarized data based exclusively on bilateral HA fittings. Overall, six studies, four involving only monaural amplification and two including both monaural and bilateral fittings, reported a significant acclimatization effect (Arkis & Burkey, 1994; Cox & Alexander, 1992; Cox et al., 1996; Gatehouse, 1992, 1993; Horwitz, 1995).

Turner et al. (1996) argued that the measure of change in auditory performance provided by HAs is limited for three reasons. First, for individuals with mild to moderate HL, the gain provided by the HA may not be sufficient to significantly improve speech recognition performance (due to the presence of a ceiling effect) when benefit is measured for speech at average preferred listening levels (i.e., input level of approximately 70 dB HL). Thus, to overcome this shortcoming (i.e., insufficient differentiation of speech abilities provided by the HA) Turner et al. (1996) suggested to use more difficult test material (e.g., lower input level), or to include participants with at least a mild to moderately severe HL who need to listen at higher presentation levels than normal hearing individuals. Second, when a speech in noise test is used to measure improvements in speech understanding performances, the benefits observed will be limited because the HA will amplify both the speech signal and the noise. Since this review was published, there have been many improvements in the technology incorporated into modern HAs, including directional microphones and noise reduction algorithms. Modern digital hearing aids may attenuate differently the signal and the noise recorded by the microphone than the HAs commercially available at the time of the studies included in the review conducted by Turner and his collaborators (Humes et al., 1999; Larson et al., 2000; Wood & Lutman, 2004). Third, an improvement on a monosyllabic word-identification task is not necessarily linearly related to changes in the ability to understand everyday speech (Boyle, Nunn, O'Connor, & Moore, 2013). Hence, test stimuli that are more representative of real-life speech, such as sentences or discourse, should be used to measure acclimatization. Finally, Turner et al., (1996) identified confounding factors that must be eliminated or controlled. These factors include: listeners' volume control setting, familiarity with the test material and ceiling or floor effect in the performances of the participants.

Ponton (1996) reviewed the non-invasive imaging techniques appropriate to identify physiological changes associated with acclimatization or deprivation. The author suggests that, if acclimatization is a consequence of functional reorganization of the brainstem auditory pathway, the auditory brainstem response (ABR) recordings should be correlated with acclimatization. Gatehouse and Robinson (1995) observed a psychophysical change in loudness function in a single participant following HA amplification as measured by N_1 amplitude. The study supports the use of Auditory Evoked Response (AER) to measure acclimatization. Moreover, the Mismatch negativity (MMN), elicited by the presentation of a deviant stimulus in an oddball paradigm, is a sensitive measure that is correlated with psychophysical performance (Kraus et al., 1995). Ponton

(1996) maintained that this sensitivity would be useful in the measurement of the physiological effects of hearing aid acclimatization. Additionally, the author suggests that positron emission tomography (PET) would provide a reliable longitudinal measure of changes in cortical metabolism following acclimatization given that Ito, Sakakibara, Honjo, Iwasaki, and Yonekura (1990) measured a metabolic increase after 3 months of cochlear implant stimulation.

Byrne and Dirks (1996) reviewed studies that employed non-speech auditory stimuli to investigate acclimatization. According to this review, measures of changes in loudness discomfort levels (LDL) following auditory amplification were first reported in the 1946 “Harvard Report” (Davis et al., 1946). Most of the later studies are consistent with the “Harvard Report” and reveal an increase of LDL following repeated testing post HA fitting (Cox, 1981; Morgan & Dirks, 1974; Walker, Dillon, Buyrne, & Christen, 1984). Unlike the LDL data, there is little evidence of change in preferred gain levels following auditory amplification (Walden, Schuchman, & Sedge, 1977). Two studies revealed that there is no significant correlation between the length of exposure to amplified sounds and the preferred gain levels (Lindley, 1999; Lindley, Palmer, Durrant, & Pratt, 2000). Also, Byrne and Dirks (1996) draw a parallel between deprivation of auditory input that affects non-speech performances and acclimatization. The poorer performances observed following auditory deprivation may be recovered, at least partially, following an acclimatization period. This finding is important and applies to all auditory abilities, including speech recognition tasks.

Limits of previously published studies

Types of signal processing

The three reviews summarized above were published more than 20 years ago (Byrne & Dirks, 1996; Ponton, 1996; Turner et al., 1996). HA technology, selection, fitting and adjustment procedures have improved substantially over the past 20 years. It can be assumed that acclimatization studies conducted in the 1990s made use of linear analogue HAs. It has been established that the benefits provided by HAs have improved with the advent of technical innovations (Granberg, Dahlstrom, Moller, Kahari, & Danermark, 2014). Yund et al. (2006) reported that the magnitude of acclimatization varied as a function of the type of signal processing algorithms incorporated into the HAs. Specifically, the investigators argued that, mostly for soft sounds, a larger acclimatization effect was observed when participants were fitted with a wide dynamic range compression (WDRC) system rather than a system that provides linear amplification. Hence, with the recent advances in HA technology and the related improvements in benefits, the acclimatization effect may have increased as well. All HAs currently available commercially are digital and include WDRC.

Monaural vs bilateral

Previously published reviews included studies in which the acclimatization effect was measured among participants that were fitted monaurally and bilaterally. Turner et al. (1996) reviewed 12 studies. In six of the studies the participants used only unilateral amplification, in one study they used bilateral amplification and in five studies they used both monaural and bilateral amplification. While no specific pattern of results can be identified based on number of HAs fitted, it is possible that the auditory deprivation that occurred in the non-amplified ear influenced the time-course and magnitude of acclimatization when the non-fitted ear is used as the control condition. For example, when compared to the performance in the non-aided ear, Gatehouse (1992) reported an improvement in speech recognition in the fitted ear using the four alternative auditory feature (FAAF). It is possible that the deprivation in the non-fitted ear increased the difference between ears which yielded an artificially larger acclimatization effect.

Outcome measures

Due to the large interindividual variability observed in the outcome measures used to investigate auditory acclimatization, it may be difficult to measure small but consistent acclimatization effects (Turner, 1996, Dawes, 2014). Additionally, the different outcome measures used make it difficult to compare results across studies (Dawes, 2014; Palmer, 1998; Turner, 1996). For example, two investigators may have used the same speech perception in noise test but in one study the dependent variable may be the signal-to-noise ratio (SNR) at which a performance level of 50% correct responses is obtained while in the other investigation the dependent variable may be the percentage of correct answers obtained at a fixed SNR. Those two outcome measures used would make it difficult to compare the results of the two studies.

Hearing aid use

Another critical factor that is not always accounted for in acclimatization studies is HA use (Philibert, Collet, Vesson, & Veuillet, 2005; Saunders & Cienkowski, 1997). In some studies, self-reported measures of HA use have been used to investigate auditory acclimatization (Reber & Kompis, 2005; Santos, Petry, & Costa, 2010). It is known that self-report measures overestimate real HA use (Solheim & Hickson, 2017). Dawes and Munro (2016) reported a significant shift of 3 dB in SNR on a speech recognition task in noise after 30 days of HA use. However, this result was observed only for a subgroup of participants who had a mean pure-tone average of more than 40 dB HL and for whom HA use exceeded six hours per day as recorded by the device's datalogging program. No improvement in speech recognition was observed for the subgroup of new HA users with a pure-tone average of less than 40 dB HL and for whom HA use was less than six hours per day. These results suggest that in order to acclimatize to the new auditory information, individuals need to be sufficiently exposed to amplified signals.

Precision of HA fittings

In order to acclimatize to auditory signals, the auditory cues that characterize the stimuli must be audible. Prescriptive formula (NAL-NL2, DSL 5.0, etc.) can be used to specify the gain required as well as to measure the audibility of the signal available to the user. In most investigations the accuracy of the gain provided by the HA is determined by measuring the real-ear insertion gain (REIG) (Dawes & Munro, 2016; Dawes, Munro, Kalluri, & Edwards, 2014; Saunders & Cienkowski, 1997). However, in some studies the REIG provided to each participant was not reported. Thus, it is not possible to verify the accuracy of the HA fitting (Santos et al., 2010; Vestergaard, 2006). Under those circumstances if the data fail to confirm an acclimatization effect it is impossible to exclude the possibility that the results are due to an inappropriate HA fitting process.

Due to the limitations of previously published studies on acclimatization, the contribution of inter-subject variability in the acclimatization data and outcomes and considering the substantial innovations in HA technology that have taken place since the beginning of the twenty-first century, a systematic review on the existence of an acclimatization effect to HAs is warranted. Results from this systematic review are clinically important in order to allow audiologists to accurately inform new HA users on magnitude and time-course of potential improvement after their HA fitting.

Research Question

Is there an auditory acclimatization effect among adults with sloping high-frequency sensorineural HL who are fitted with bilateral HAs for the first time? If so, what is the time-course and magnitude of the acclimatization effect?

Methods

Design

The Centre for Reviews and Dissemination (CRD) guideline for undertaking reviews in health care (Centre for Reviews and Dissemination, 2008) and the GRADE Handbook for grading the quality of evidence and the strength of recommendations (GRADE Working Group, 2013) were consulted to conduct the systematic review. As stipulated in those guidelines, a systematic review should be based on a protocol which includes background information, a review question, inclusion criteria, study selection, data extraction, quality assessment of the studies, data synthesis and dissemination.

Eligibility criteria

Considering that the past evidence suggests that the time-course of the auditory acclimatization is at least 4 weeks in duration, only longitudinal repeated designs and randomized controlled trial (RCT) that extend to at least one-month post HA fitting were considered in the present review (Dawes & Munro, 2016; Gatehouse, 1992). According to Arlinger et al. (1996), deprivation is defined as “a systematic decrease over time in auditory performance associated with the reduced availability of acoustic information”. Although there is little evidence concerning the time course or the magnitude of the deprivation effect as well as the effect of bilateral deprivation, it is accepted that monaural amplification leads to auditory deprivation in the non-amplified ear (Boisvert, McMahon, & Dowell, 2012; Munro, 2008; Wieselberg & Iorio, 2012). To isolate the acclimatization effect from the deprivation effect, all changes in outcome measures had to be attributable to the use of bilateral HAs. Participants in studies included in the review had to be middle aged (45 to <60 years of age) or older adults (≥60 years of age) with a symmetrical sensorineural HL and fitted with HAs for the first time (i.e., no previous experience with HA use). In order to include only non-linear HAs with WDRC (analogue or digital) which became available in the early 1990s, an inclusion criterion in this systematic review specified that only studies published after 1990 were included. Articles in English or French published in peer-reviewed scientific journals were considered.

Outcomes

Based on previously published studies on auditory acclimatization to HAs three categories of outcomes were considered in the present review: behavioural measures (SIN, QuickSIN, Speech recognition is noise, etc.); self-report measures (SADL, SSQ, HAPI, etc.); and electrophysiological measures (ABR, FFR, etc.)

Search Strategy

The following databases and search engines were consulted: Medline, CINAHL and Scopus. The following combination of keywords were used for all databases: [hearing aid] AND [(acclimatization) OR (adaptation)] AND (hearing loss). Also, Google Scholar and reference lists of the studies retained for the review were searched.

Data collection and procedures

Studies identified by the literature search were first screened by their title. Titles that did not meet the inclusion criteria were excluded (essentially studies on cochlear implants, tinnitus management and bone-anchored HAs). Then, to validate that the selected articles met the inclusion criteria, a screening by abstract was conducted. The ultimate screening was accomplished by reading the complete article of the documents retained to this point. This led to a final selection of studies that were included in the complete review process. The selection of the studies, the screening by titles, the validation by abstracts, the screening by full-text and the critical appraisal were done independently by two of the authors (DW and MH) on the first 10 titles. The inter-judge agreement was verified. When there was a discrepancy between reviewers, it was solved by mutual agreement. Successive review rounds of 10 more titles were conducted until an inter-judge agreement of 90% was reached.

Critical appraisal

The methodology proposed by the GRADE working group was applied to assess the scientific quality of the reviewed articles (GRADE Working Group, 2013). For each outcome and for all the studies, the GRADE approach also considers the consistency and precision of the estimated effect, the directness of outcome measurements, the publication biases and it outlines any particular strength. This procedure yields a review process that is thorough and transparent.

According to the GRADE handbook for assessing the quality of evidence and the strength of recommendation, the scientific quality of the reviewed articles is rated by outcomes and across studies on a four-point scale (high, moderate, low and very low). All outcomes were assessed for risk of bias, consistency, directness, precision, and publication bias. In accordance with the GRADE methodology, the body of evidence was rated as high (very confident that the true effect is close to the effect estimate), moderate (moderately confident), low (limited confidence), or very low (little confidence).

Results

Study Flow

The study selection process identified a total of 1713 articles that were reduced to 633 after the duplicates were removed. A title review of these 633 articles excluded 495 articles reducing the number to 138. An abstract review excluded an additional 109 articles and the full-text review narrowed the total articles to be included in the review to 14.

The literature search strategy flow chart is shown in Figure 1.

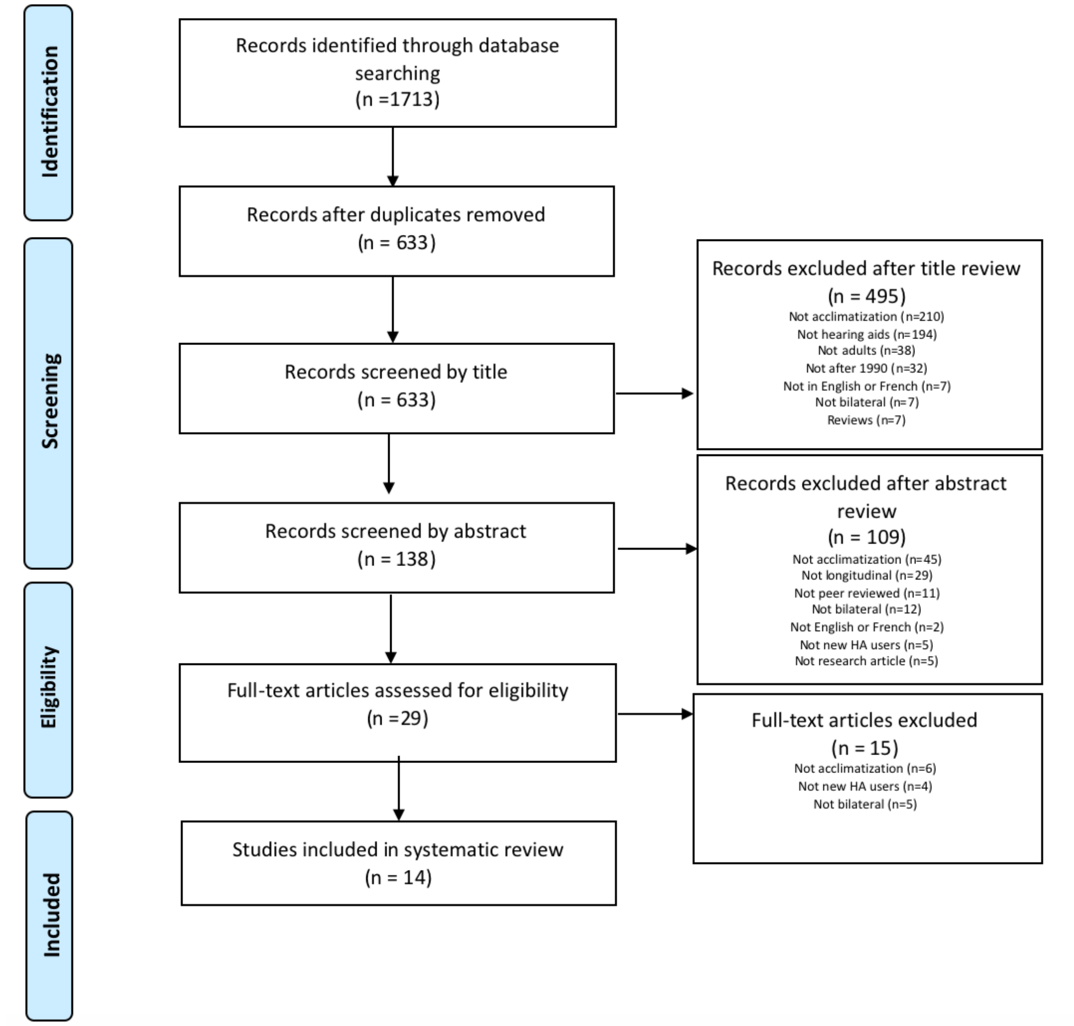


Figure 0.1. Literature search strategy flow chart

Table 4.1. Study, Design, Participant Characteristics, Outcome Measures, and Results for studies included in the systematic review.

Study	Design	Participants	Pre-post outcome measures and Results	Notes
1. Dawes and Munro (2016)	Longitudinal repeated measures with observations at Day 0, 1-, 7-, 14- and 30-day post-fitting.	Inclusion criteria: - PTA (0.5, 1, 2 and 4 kHz) >20 dB HL and <70 dB HL Exclusion criteria - Fluctuating or recent changes in hearing level - Asymmetry in air conduction thresholds >15 dB - Air-bone gap >15 dB at any test frequency - Abnormal middle ear function 35 new HA users: - No previous HA experience - 70 years of age (SD=10) - PTA (0,5, 1, 2 and 4 kHz): 38 dB HL (SD=9) - No information on gender 20 experienced HA users: - At least 1 year of experience with HA - 78 years of age (SD= 8)	Speech in noise (SIN) Auditory distraction task Auditory distraction questionnaire Improvement in aided SIN was associated with self-reported reduction in the intrusiveness of background sound Primary finding: Significant improvement on the SIN for new HA users with more severe HLes and those who used their HAs consistently.	REIG was measured Datalogging accounted for Distraction task and questionnaire not validated outcomes Inclusion of control group

		- PTA: 46 dB HL (SD=7) - No information on gender Subgroup of 10 participants amongst the new HA users: - PTA >40 dB HL and who use their HAs >6 hours HAs: - Oticon Spirit Zest for new HA users: digital, 16 channels, nonlinear, BTE - Previously owned HA for experienced HA users - NAL-NL2 (measured with REIG) - HA use accounted for but not an inclusion criterion (monitored through datalogging)		
2. Dawes et al. (2014)	Longitudinal repeated measures with observations at day 0 and 12-weeks post-fitting.	Inclusion criteria: - PTA (2-6 kHz) >40 dB - Symmetrical HL - Sensorineural HL Exclusion criteria: - Fluctuating or recent changes in hearing level - Asymmetry in air conduction thresholds >15 dB at two or more frequency - Air-bone gap >15 dB at any test frequency - Abnormal middle ear function	FAAF 65 dB SPL FAAF 75 dB SPL Primary finding: Significant improvement on the FAAF for the new HA users and the experienced HA users. Improvement is associated with a practice effect.	Post-hoc can't be used because the authors pooled bilateral and unilateral users. REIG was measured Large variability in HA use (1 to 13 hours / day) Inclusion of control group

		16 new HA users: - History of HL of at least 1-year duration - No previous HA experience - 67 years of age (SD=11) - PTA (2 to 6 kHz): 50 dB HL (SD=9) - No information on gender 9 experienced HA users: - At least 1 year of experience with HA - HA use of at least 6 hours per day - 73 years of age (SD=6) - PTA (2 to 6 kHz): 57 dB HL (SD=13) - No information on gender HAs: - Starkey Radius BTE (N=7) or Destiny CIC (N=25) for new HA users: digital, nonlinear, 8 channel, noise management activated. - Previously owned HA for experienced HA users - NAL-NL1(measured with REIG) - HA use accounted for but not an inclusion criterion (monitored through datalogging)		

3. Habicht et al. (2018)	Longitudinal repeated measures with observations at 0-, 12- and 24-weeks post-fitting.	Inclusion criteria: - From 60 to 80 years of age - Bilateral, sloping, sensorineural HL from 40 to 80 dB HL between 3 and 8 kHz - Self-reported normal or corrected-to-normal vision - 6 hrs of HA use per day 16 new HA users (up to 12 weeks) - No previous HA experience - 73 years of age (from 64 to 79) - PTA (0.5 to 4 kHz): 38 dB HL (from 30 to 46) - Daily HA use: 9.1 hrs/day (from 6 to 12) - No information on gender 14 experienced HA users (up to 12 weeks) - Minimum of 1 year of HA experience - 74 years of age (from 68 to 80) - PTA (0.5 to 4 kHz): 43 dB HL (from 37 to 51) - Daily HA use: 11.4 hrs / day (from 6 to 16) HAs: - Sivantos pure micon 7mi RIC, nonlinear, noise management activated. - NAL-NL1 (measured with REIG)	SRT80 low linguistic complexity SRT80 high linguistic complexity Response times Processing times: ERP measurements Primary findings: Significant improvement on processing times for new HA users. HA use has a positive influence on speech comprehension abilities. Effect of auditory acclimatization on electrophysiology emerges after 24 weeks. Effect of acclimatization on cognitive-linguistic processes may take several months.	REIG was measured HA use of at least 6 hrs/ day Potentially underpowered study Inclusion of control group

		- HA use accounted for. - Previously owned HAs for experienced HA users		
4. Karawani et al. (2018)	Controlled and randomized repeated measures with observations at day 0 and 6-months post-fitting.	Inclusion criteria: - 60-84 years of age - Mild-to-moderate sensorineural HL - No neurologic disorders - English as first language - No previous HA experience 20 New HA users - 75 years of age (SD=6.3) - 9 women/22 men - PTA (0.5 to 4 kHz): 43.2 dB HL (SD=6.7) 15 Non HA users - 74 years of age (SD=5.6) - 6 women/9 men - PTA (0.5 to 4 kHz): 38.47 dB HL (SD=6.9) HAs: - Widex Dream 440 RIC for new HA users, 15 frequency channels, directional microphones and noire reduction algorithms. - NAL-NL2 (measured with REIG)	QuickSIN APHAB SSQ FFR Primary findings: (1) increase of satisfaction with HAs over time, (2) HA use delayed temporal processing of speech cues, (3) significant correlation between physiologic responses of perceptual measures and subjective benefits of HA.	Funded by manufacturing company Control group was comprised of non HA users (wore HAs only for testing sessions) Inclusion of control group

		- Minimum of 8 hours of HA use per day (monitored through datalogging).		
5. Laperuta (2012)	Longitudinal repeated measures with observations at 1-, 3- and 6-months post-fitting.	Inclusion criteria: - Bilateral sensorineural HL - PTA (0.5, 1, 2, 3 and 4 kHz) between 40 and 70 dB HL. - Use of behind the ear nonlinear HA with no previous HA experience - Over 60 years of age 22 New HA users: - Between 63 and 87 years of age - 11 women/ 11 men HAs: - REIG done - No datalogging information - No prescription formula information - Gradual increase of HA gain up to 6 months.	Satisfaction in Daily Life (SADL) Primary finding: Significant improvement of satisfaction with HAs after 3 months of HA use.	Prescription formula not mentioned Adjustments in gain output was done based on complaints (gradual increase of gain) Possible carry over effect Ethics approval not mentioned No control group
6. Lavie et al. (2013)	Longitudinal repeated measures with observations at day 0, 1,	Inclusion criteria: - Symmetric sensory HL - PTA (0.5, 1, 2 and 4 kHz) between 30 and 70 dB - Flat or mild-moderate slope audiograms	Dichotic listening scores for monosyllabic words	Small sample size No post-hocs analyses available

	2- and 3.5-months post-fitting.	- Symmetric speech discrimination scores (≥60%) - No previous HA experience - Cognitively fit (as measured by the MMSE, digit span and language comprehension test) 9 new HA users (without training): - Between 64-88 years of age - 16 women/ 20 men 27 new HA users (with training) - Not relevant for this review HAs: - High-end bilateral digital HAs - HA use accounted for but not an inclusion criteria (monitored through datalogging) - No information on manufacturing company.	Primary finding: Improvement of satisfaction with HAs after 3 months. Improvement of unaided dichotic listening scores for both groups (data not available since both groups were pooled together for data analyses)	REIG not mentioned Large variability in HA use (M=5.7 hrs/day, SD=2.3 hrs/day) No control group
7. Petry et al. (2010)	Longitudinal repeated measures with observations at 14- and 90-days post-fitting.	Inclusion criteria: - Over 18 years of age - Post-lingual Mild to moderate SNHL - Speech recognition threshold ≤ 65 dB SL in the best ear - Referred the use of bilateral HAs - No previous HA experience	SRTS: Sentence recognition threshold in silence SRTN: Sentence recognition threshold in noise	Large individual differences may hide improvements. REIG not mentioned HA use not accounted for.

		- No neurological or altered verbal fluency conditions. 27 new HA users: - 61 to 78 years of age (M=68.85) - 15 women/ 12 men HAs: - No information	SRPRS: Sentence recognition percentage rate in silence SRPRN: Sentence recognition percentage rate in noise Primary finding: No significant improvement of performances.	No control group
8. Philibert et al. (2005)	Longitudinal repeated measures with observations before fitting, day 0, 1-, 3- and 6-months post-fitting.	Inclusion criteria: - Symmetrical, sloping SNHL - Right-handed on the Edinburgh handedness scale. - No previous HA experience 8 new HA users (only 5 participated to the electrophysiological testings): - 69 to 78 years of age (M=74) - 4 women/ 4 men - PTA (0.5, 1, 2 and 4 kHZ): 45.23 (SD=6.16) HAs: - 6 BTE and 2 ITE - Digital technology	Loudness-scaling task: significant improvement at 2 kHz for the “Very loud” category DLI task: At 95 dB SPL, significant improvement at 2 kHz Click-evoked ABR: Reduction of wave V latency in right ears.	Small sample size HA use was ≥8 hrs/ day as monitored through a questionnaire Predicted REIG measures in a 2cc coupler at 65 dB SPL. Modification of gain was done after 1 month of HA use. No control group

		- No datalogging information		
9. Pinheiro et al. (2012)	Longitudinal repeated measures with observations before fitting and 3 to 10 months post-fitting.	Inclusion criteria: - No neurological changes - Brazilian Portuguese as the firest language - Bilateral moderate to moderately-severe SNHL from 0.5 to 4 kHz - Normal tympanometry - No previous HA experience 60 New HA users: - 61 to 85 years of age (M= 71.7). - 20 women/ 20 men - PTA (0.5 to 4 kHz): 50.4 dB NA HAs: - Micro or intra canal HAs - No information on prescription formula or REIG - HA use was accounted for (M=9.1 hrs/day).	PISRL Percentage of speech recognition: Significant improvement DDT: Dichotic digit test Primary finding: Significant improvement on the speech recognition test and significant improvement on the dichotic digit test for the left ear.	Experimental tests were conducted unaided. REIG and prescription formula not mentioned Average HA use: 9.1 hrs/day Second testing sessions were done at different times (from 3 to 10 months post-fitting). No control group
10. Reber et Kompis (2005)	Longitudinal repeated measures with observations at day of fitting, 2 weeks and 6 months post-fitting.	Inclusion criteria: - SNHL within the fitting range of the HA manufacturer - Valid HA prescription according to the Swiss regulations - Willingness to try HAs	Freiburger monosyllabic word-test in quiet at 50, 65 and 80 dB SPL Basler sentence test in noise	Adjustments differed between participants HA use was monitored through a questionnaire.

		- No previous HA experience 23 new HA users - 40 to 76 years of age (M= 64) - PTA (0.5 to 4 kHz): 40 dB HL (SD=16) - HAs: - ITE Bernafon HAs (CIC, ITC, ITE), digital, FFT processing, channel-free amplification algorithms. - % of NAL-NL1 prescription differed between participants. - No datalogging information - REIG done.	Primary findings: Significant improvement with and without HAs in quiet and in noise.	No SD for Basler sentence test in noise results No control group
11. Saunders & Cienkowski (1997)	Longitudinal repeated measures with observations at day 0, 1-, 2- and 3-months post-fitting.	Inclusion criteria: - Mild to moderate, symmetrical SNHL 24 new HA users: - 60 to 75 years of age (M=69) - PTA (0.5 to 4 kHz): 45.3 dB HL (SD=6.2) - 0 women/ 24 men - No previous HA experience 24 experienced HA users:	SRT in quiet (SRT-Q) Performance- speech recognition thresholds in noise (PSRT-N) Subjective- speech recognition thresholds in noise (SSRT-N)	HA use was monitored through a questionnaire. No SD for SRT in quiet. Limited generalizability of results (all men veterans) Inclusion of control group

		- 55 to 75 years of age (M= 69) - PTA (0.5 to 4 kHz): 48 dB HL (SD=5.8) - 0 women/ 24 men HAs: - REIG done - No datalogging information - HA configurations differed between participants - No information on prescription formula	Primary finding: No significant improvement on the SRT-Q, PSRT-N and SSRT-N.	
12. Stecker et al. (2006)	Longitudinal repeated measures with observations at day 0, 1-, 2-, 4- and 8-weeks post-fitting.	Inclusion criteria: - Bilateral high-frequency SNHL - Bone conduction thresholds within 10 dB from air conduction thresholds. 11 new HA users (without training): - 0 women/ 11 male - From 50 to 80 years of age (M=69) - PTA (0.5 to 4 kHz): 43 dB HL (SD=9) HAs: - Digital HAs, 2, 3 or 4 channels, low-to-moderate compression ratios (1 to 2) - NAL-NL1 verified by REIG.	NST Primary finding: Significant improvement of 2.4 % by week 8.	Small sample size Limited generalizability of results (all male veterans) No information on HA use Ethics approval not mentioned No control group

13. Vestergaard (2006)	Longitudinal repeated measures with observations at 1-, 4- and 13-weeks post-fitting.	Inclusion criteria: - Sloping HL 25 HA users (5 experienced and 20 new): - 3 women/ 22 men - Average of 60.4 years of age (SD= 10.8) - PTA (p.5 to 4 kHz): 42.5 dB HAs: - Oticon Adapto, non linear, multiband, 2 channel compression. - ITE HAs - No datalogging information - REIG not mentioned.	Glasgow HA Benefit Profile (GHABP) International Outcome Inventory for HA (IOI-HA) HA Performance Questionnaire (HAPQ) Satisfaction with Amplification in Daily Life (SADL) Primary findings: Significant improvement on the GHABP and the IOI-HA for new HA users that wore their HA's more than 4 hrs/day.	REIG not mentioned Small sample HA use was monitored through a questionnaire. GHABP and IOI-HA not validated in Danish Inclusion of control group
14. Yund et al. (2006)	Longitudinal repeated measures with observations at 0-, 1-, 2-, 4-, 8-, 16- and 32-weeks post-fitting.	Inclusion criteria: - No previous HA experience - Sloping bilateral and symmetrical HL 39 new HA users: - From 43 to 84 years of age (M=66.7) - 10 women/ 29 men - PTA (0.5 to 4 kHz): 39.4 dB HL (SD=10.5) HAs:	NST at SNR 15, 5 and -5 PHAB HAPI Primary findings: Significant improvement of 2.3% after 32 weeks for participants with WDRC fittings.	Limited generalizability of results (all veterans) HA use not accounted for No control group

		- ITC with independent compression channels - Canta 730 from GN Resound and Altair from Sonic Innovations. - 2 types of fitting: linear and WDRC - No datalogging information - NAL-R verified by REIG.		

Study characteristics

Design methodology

All of the studies included in the review consisted of a longitudinal pre-post repeated measures design. Of the 14 studies included, only five included a control group that consisted of experienced HA users (Dawes & Munro, 2016; Dawes et al., 2014; Habicht, Finke, & Neher, 2018; Saunders & Cienkowski, 1997; Vestergaard, 2006). Karawani et al. (2018) was the only study that employed a controlled randomized design which included a group of new HA users and a group of non-HA users. Time lapse between initial and final measurement varied from 1 to 10 months post-fitting (M=4.5 months).

Participants characteristics

Age: All studies included only middle-aged (45 to <60 years of age) or older adults (≥60 years of age) as seen in Table 1. Nine studies included only older adults while five studies also included middle-aged participants (Dawes et al., 2014; Reber & Kompis, 2005; Stecker et al., 2006; Vestergaard, 2006; Yund et al., 2006).

Gender: Most of the studies included both male and female participants and five had a near 50/50 male-to-female ratio (Laperuta & Fiorini, 2012; Lavie, Attias, & Karni, 2013; Petry, Santos, & Costa, 2010; Philibert et al., 2005; Pinheiro, Iorio, Miranda, Dias, & Pereira, 2012). Yund et al. (2006) and Vestergaard (2006) had a low female-to-male ratio, 34% and 14%, respectively. Saunders and Cienkowski (1997) and Stecker et al. (2006) enrolled only males in their studies because all participants were veterans and potential female candidates were most likely scarce. Reber and Kompis (2005), Habicht et al. (2018), Dawes et al. (2014) and Dawes and Munro (2016) did not report the gender of the participants.

Degree of Loss: Although audiometric configuration and degree of HL varied, all new and experienced HA users had a symmetrical high-frequency sloping SNHL. In most of the studies, HL was reported as the participant's pure-tone average at 0.5, 1, 2 and 4 kHz. The average HL varied from 38 to 50 dB HL (Dawes & Munro, 2016; Habicht et al., 2018; Karawani, Jenkins, & Anderson, 2018; Philibert et al., 2005; Pinheiro et al., 2012; Reber & Kompis, 2005; Saunders & Cienkowski, 1997; Stecker et al., 2006; Vestergaard, 2006; Yund et al., 2006). Dawes et al. (2014) reported a PTA of 50 dB HL at 2-6 kHz. Laperuta and Fiorini (2012) and Lavie et al. (2013) did not provide the degree of HL of the participants but their inclusion criteria stipulated that the PTA (0.5, 1, 2 and 4 kHz) of their participants had to be between 40 and 70 dB HL and between 30 and 70 dB HL, respectively. Similarly, Petry et al. (2010) did not report the degree of HL of the participants but their inclusion criteria included having a mild to moderate sloping SNHL and a SRT of ≤65 dB SPL.

HA experience/control group: All studies included new HA users without prior experience, but only six of the 14 studies included a control group. Karawani et al. (2018) included a group of non-HA users with HL as a control group. The five other studies included experienced HA users as the control group. In three of the studies, participants in the experienced HA user group had at least 1 year of HA experience (Dawes & Munro, 2016; Dawes et al., 2014; Habicht et al., 2018). Saunders and Cienkowski (1997) and Vestergaard (2006) did not specify the HA experience of their control group.

HA use: Four of the studies did not consider or failed to report the HA use of their participants (Laperuta & Fiorini, 2012; Petry et al., 2010; Stecker et al., 2006; Yund et al., 2006). Four studies reported HA use of at least 6 hrs/day as measured by datalogging (Dawes & Munro, 2016; Habicht et al., 2018; Karawani et al., 2018; Pinheiro et al., 2012). Two studies also extracted the datalogging information from the HAs of their participants but reported large variability in HA use (from 1 to 13 hrs/day) (Dawes et al., 2014; Lavie et al., 2013). Finally, four studies measured

HA use through self-reported assessments (Philibert et al., 2005; Reber & Kompis, 2005; Saunders & Cienkowski, 1997; Vestergaard, 2006).

Hearing Aids

Type of signal processing: In nine of the studies it was specified that the participants used digital HAs (Dawes & Munro, 2016; Dawes et al., 2014; Habicht et al., 2018; Karawani et al., 2018; Lavie et al., 2013; Reber & Kompis, 2005; Stecker et al., 2006; Vestergaard, 2006; Yund et al., 2006). In the remaining 5 studies the type of processing incorporated into the HAs was not mentioned (Laperuta & Fiorini, 2012; Petry et al., 2010; Philibert et al., 2005; Pinheiro et al., 2012; Saunders & Cienkowski, 1997).

Make and models: Dawes and Munro (2016) used the Oticon Spirit Zest HAs that include 16 adjustable channels. In the Vestergaard (2006) study, published 10 years earlier, the participants were fitted with Oticon Adapto HAs that have 7 channels. In terms of design, three studies fitted the new HA users with behind-the-ear (BTE) models only (Dawes & Munro, 2016; Habicht et al., 2018; Karawani et al., 2018), four used in-the-ear (ITE) models only (Pinheiro et al., 2012; Reber & Kompis, 2005; Vestergaard, 2006; Yund et al., 2006) and two studies included both BTE and ITE HAs (Dawes et al., 2014; Philibert et al., 2005). The remaining five studies did not report the models of the HAs used.

Prescription formula: One study used the NAL-NL2 prescription formula (Dawes & Munro, 2016), four studies used the NAL-NL1 formula (Dawes et al., 2014; Habicht et al., 2018; Reber & Kompis, 2005; Stecker et al., 2006) and one study used the NAL-R formula (Yund et al., 2006). The seven remaining studies did not report the prescription formula that was used.

Verification: Although the prescription formula was not always indicated, nine of the studies reported measuring REIG after HA fitting (Dawes & Munro, 2016; Dawes et al., 2014; Habicht et al., 2018; Karawani et al., 2018; Laperuta & Fiorini, 2012; Reber & Kompis, 2005; Saunders & Cienkowski, 1997; Stecker et al., 2006; Yund et al., 2006). Laperuta and Fiorini (2012) acknowledged that the gain provided differed from the recommended prescribed gain and that adjustments were made on the basis of participant complaints. The purpose of the study by Reber and Kompis (2005) was to measure the acclimatization effect in new HA users using three different fitting protocols. In that study two of the three new HA user groups were intentionally not fitted according to a prescriptive formula. Philibert et al. (2005) measured predicted HA gain output in a 2-cc coupler instead of REIG. Finally, four studies did not report measuring HA gain output level (Lavie et al., 2013; Petry et al., 2010; Pinheiro et al., 2012; Vestergaard, 2006).

Outcome Measures

Given the large variety of outcome measures used across studies, results were divided in three categories of outcomes: behavioural, self-report scales and electrophysiological.

Behavioural measures: Twelve studies used at least one behavioural task to measure the acclimatization effect. A wide variety of behavioural tasks were employed as outcome measures. The outcome measures used are listed in Table 2. Only statistically significant acclimatization effects were considered in reporting the range of absolute improvement scores included in Table 2.

Self-report scales: Six studies used self-report questionnaires to measure different changes in perceived HA use. Specifically, changes in HA use was measured in the following domains: global satisfaction with HAs, performance in speech recognition in quiet and in noise, ease of communication, adverseness to background noise and distortion of sounds (Dawes & Munro, 2016; Karawani et al., 2018; Laperuta & Fiorini, 2012; Saunders & Cienkowski, 1997; Vestergaard, 2006; Yund et al., 2006). A summary of these findings is presented in Table 3.

Electrophysiological measures: Three studies measured plasticity of the central auditory pathway following acclimatization to HAs using electrophysiological measures. The electrophysiological results from Habicht et al. (2018) are not published and they were not considered in the systematic review. Karawani et al. (2018) used frequency-following response (FFR) to investigate changes at the cortical level following amplification. Philibert et al. (2005) used auditory brainstem response (ABR) to assess changes in the brainstem response following acclimatization to HAs. A summary of these findings is reported in Table 4.

Study quality

The quality of evidence of the studies included in the review was assessed according to GRADE's framework. Quality appraisal was conducted by outcome variables. Particular attention was given to study limitations specific to HA acclimatization measures such as the absence of a control group, no measure of HA use as determined by a datalogging feature, no mention of REIG measures, small sample size and studies funded by HA manufacturing companies. Then, overall quality was assessed by outcome, across studies, for study limitations, inconsistency, indirectness, imprecision and particular strengths. Inconsistency was judged on the heterogeneity of findings across studies for each outcome. Indirectness appraisal was based on whether the outcome accurately measured auditory acclimatization. The assessment of imprecision was based on the number of events and the confidence intervals. Particular strength was only granted to the study by Karawani et al. (2018) which used a randomized control trial design.

The general quality of outcome variables was either assessed as low or very low. The poor quality of evidence is explained by many limitations. First, as per GRADE's framework, non-randomized control trials are automatically identified as low quality. Also, based on previous power analyses, study limitation was increased when studies didn't include a control group and if they had fewer than 20 participants per group. Outcomes were graded with serious imprecision if the confidence interval was large. Moreover, measuring auditory abilities for HA users in an unaided condition may not accurately measure an acclimatization to new auditory cues. These outcomes were downgraded in the assessment of the indirectness criterion. Self-report scales can be considered to be an indirect measure of auditory acclimatization. For this reason, all self-reported outcomes were automatically downgraded in the assessment of the indirectness criterion. A summary of quality assessment is presented in Table 2, 3 and 4.

Table 4.2 Quality assessment and Summary of findings: Behavioural outcomes

Outcome (measurement unit)	**No. of studies (participants)**	**Limitations**	**Inconsistency**	**Indirectness**	**Imprecision**	**Publication bias**	**Particular strengths**	**Significant improvement (number of studies)**	**Range of reported absolute improvement**	**Quality**
Monosyllable in quiet at 50 dB- Unaided (%)	1 (23)	Very serious	Not applicable	Not serious	Serious	Not detected	No	Yes	+9%	Very low
Monosyllable in quiet at 65 dB- Unaided (%)	2 (57)	Very serious	Serious	Not serious	Serious	Not detected	No	No (1) Yes (1)	NS to +3%	Very low
Monosyllable in quiet from 75 to 80 dB- Unaided (%)	3 (117)	Very serious	Serious	Not serious	Serious	Not detected	No	No (2) Yes (1)	NS to 4%	Very low
Monosyllable in quiet at 50 dB- Aided (%)	1 (23)	Very serious	Not applicable	Not serious	Serious	Not detected	Large effect	Yes	+ 32%	Moderate
Monosyllable in quiet et 65 dB SPL - Aided (%)	2 (57)	Very serious	Not serious	Not serious	Not serious	Not detected	No	No	NS	Low
Monosyllable in quiet from 75 to 80 dB- Aided (%)	2 (57)	Very serious	Not serious	Not serious	Not serious	Not detected	No	No	NS	Low

Sentence recognition in quiet presented at 65 dB A- Aided (%)	1 (27)	Very serious	Not applicable	Not serious	Serious	Not detected	No	No	NS	Very low
Sentence recognition in noise- presented between 61 to 74 dB SPL (0 SNR)- Aided- (%)	2 (38)	Very serious	Serious	Not serious	Serious	Not detected	No	No (1) Yes (1)	NS to +2.22%	Very low
Sentence recognition in noise- presented between 65 to 81 dB SPL (+10 SNR)- Aided (%)	1 (11)	Very serious	Not applicable	Not serious	Serious	Not detected	No	Yes	+2.9%	Very low
Sentence recognition in noise (Average performance at -15, 5 and 15 SNR)- Aided (%)	1 (38)	Serious	Not applicable	Not serious	Not serious	Not detected	No	Yes	+2.1%	Low
Sentence recognition in noise- presented from 65 to 70 dB HL or SPL- 50% performance- Aided (SNR)	4 (105)	Serious	Serious	Not serious	Not serious	Not detected	RCT (1)	No (3) Yes (1)	NS to +2.4 dB	Very low

Sentence recognition in noise- presented at most comfortable level- Aided (SNR)	1 (24)	Serious	Not applicable	Not serious	Serious	Not detected	No	No	NS	Moderate
Sentence recognition in noise- presented from 65 to 70 dB HL or SPL- 50% performance- Unaided (SNR)	1 (15)	Not serious	Not applicable	Serious	Serious	Not detected	RCT	No	NS	High
Sentence recognition in noise- presented at most comfortable level (SNR)- Unaided	1 (24)	Serious	Not applicable	Serious	Serious	Not detected	No	No	NS	Moderate
Sentence recognition threshold in silence (dB)- Aided	2 (51)	Very serious	Serious	Not serious	Serious	Not detected	No	No (1) Yes (1)	NS to +0.78 dB	Very low
Dichotic listening (overall change)	2 (66)	Very serious	Serious	Serious	Serious	Not detected	No	No (1) Yes (1)	NS to +10.3%	Very low
Dichotic listening (left or non dominant ear)	2 (66)	Very serious	Not serious	Serious	Serious	Not detected	No	Yes	+6 to +13.8%	Very low
Dichotic listening (right or dominant ear)	2 (66)	Very serious	Serious	Not serious	Serious	Not detected	No	No (1) Yes (1)	NS to +6.9%	Very low

Discrimination limen- 0.5 kHz- 75 dB	1 (8)	Very serious	Not applicable	Not serious	Serious	Not detected	No	No	NS	Very low
Discrimination limen- 0.5 kHz- 95 dB	1 (8)	Very serious	Not applicable	Not serious	Serious	Not detected	No	Yes	+1.1 dB	Very low
Discrimination limen- 2 kHz- 75 dB	1 (8)	Very serious	Not applicable	Not serious	Serious	Not detected	No	No	NS	Very low
Discrimination limen- 2 kHz- 95 dB	1 (8)	Very serious	Not applicable	Not serious	Serious	Not detected	No	Yes	+1.45 dB	Very low
Auditory distraction (%)	1 (35)	Serious	Not applicable	Serious	Not serious	Not detected	No	No	NS	Moderate
Loudness scaling task- 0.5 kHz- Soft and very soft (dB SPL)	1 (8)	Very serious	Not applicable	Not serious	Very serious	Not detected	No	No	NS	Very low
Loudness scaling task- 0.5 kHz- Ok, loud and very loud (dB SPL)	1 (8)	Very serious	Not applicable	Not serious	Serious	Not detected	No	No	NS	Very low
Loudness scaling task- 2 kHz- Soft and very soft (dB SPL)	1 (8)	Very serious	Not applicable	Not serious	Very serious	Not detected	No	No	NS	Very low
Loudness scaling task- 2kHz- Ok, loud and very loud (dB SPL)	1 (8)	Very serious	Not applicable	Not serious	Serious	Not detected	No	Yes	+5.67 dB	Very low

Response time- Low linguistic complexity (msec)	1 (10)	Not serious	Not applicable	Serious	Serious	Not detected	No	No	NS	Moderate
Response time- high linguistic complexity	1 (10)	Not serious	Not applicable	Serious	Serious	Not detected	No	No	NS	Moderate
Processing time (msec)	1 (10)	Not serious	Not applicable	Serious	Serious	Not detected	No	Yes	+425 msec.	Moderate

Table 4.3. Quality assessment and Summary of findings: Self-reported outcomes

Outcome	**No. of studies (participants)**	**Limitations**	**Inconsistency**	**Indirectness**	**Imprecision**	**Publication bias**	**Particular strengths**	**Significant improvement (number of studies)**	**Range of reported absolute improvement across studies**	**Quality**
Subjective speech in noise (SNR)	1 (24)	Serious	Not applicable	Very serious	Serious	Not detected	No	No	NS	Very low
GHABP (%)	1 (20)	Very serious	Not applicable	Serious	Not serious	Not detected	No	No	NS	Low
IOI-HA	1 (20)	Very serious	Not applicable	Serious	Not serious	Not detected	No	No	NS	Low

SADL	2 (42)	Very serious	Serious	Serious	Not serious	Not detected	No	No (1) Yes (1)	NS to +0.8%	Very low
HAPQ	1 (20)	Very serious	Not applicable	Serious	Not serious	Not detected	No	No	NS	Very low
APHAB- EC	1 (20)	Very serious	Not applicable	Serious	Not serious	Not detected	No	Yes	+11.4 %	Moderate
APHAB- RV	1 (20)	Very serious	Not applicable	Serious	Not serious	Not detected	No	Yes	+8.6%	Moderate
APHAB- BN	1 (20)	Very serious	Not applicable	Serious	Not serious	Not detected	No	Yes	+5.7%	Moderate
APHAB- AV	1 (20)	Very serious	Not applicable	Serious	Not serious	Not detected	No	Yes	+22.8%	Moderate
PHAB	1 (19)	Very serious	Not applicable	Serious	Not serious	Not detected	No	No	NS	Very low
HAPI	1 (19)	Very serious	Not applicable	Serious	Not serious	Not detected	No	No	NS	Very low
SSQ: Speech	1 (20)	Serious	Not applicable	Serious	Not serious	Not detected	No	Yes	+15.1%	Moderate
SSQ: Spatial	1 (20)	Serious	Not applicable	Serious	Not serious	Not detected	No	No	NS	Moderate

SSQ: Qualities	1 (20)	Serious	Not applicable	Serious	Not serious	Not detected	No	No	NS	Moderate
Distraction questionnaire (%)	1 (35)	Very serious	Not applicable	Very serious	Not serious	Not detected	No	No	NS	Very low

Table 4.4. Quality assessment and Summary of findings: Electrophysiological outcomes

Outcome	**No. of studies (participants)**	**Limitations**	**Inconsistency**	**Indirectness**	**Imprecision**	**Publication bias**	**Particular strengths**	**Significant improvement (number of studies)**	**Range of reported absolute improvement across studies**	**Quality**
FFR - Latency- 65 dB SPL- Aided (ms)	1 (20)	Not serious	Not applicable	Not serious	Not serious	Not detected	RCT	Yes	-0.61	High
FFR - Latency- 65 dB SPL- Unaided (ms)	1 (20)	Not serious	Not applicable	Serious	Not serious	Not detected	RCT	No	NS	Moderate
FFR - Latency- 80 dB SPL- Aided (ms)	1 (20)	Not serious	Not applicable	Not serious	Not serious	Not detected	RCT	Yes	-0.2	High
FFR - Latency- 80 dB SPL- Unaided (ms)	1 (20)	Not serious	Not applicable	Serious	Not serious	Not detected	RCT	No	NS	Moderate

FFR - Peak Latency- Noise-Aided (ms)	1 (20)	Not serious	Not applicable	Not serious	Not serious	Not detected	RCT	No	NS	High
FFR -Peak Latency- Noise-Unaided (ms)	1 (20)	Not serious	Not applicable	Serious	Not serious	Not detected	RCT	No	NS	Moderate
Wave I- Latency- RE (ms)	1 (5)	Very serious	Not applicable	Not serious	Serious	Not detected	No	No	NS	Very low
Wave I- Latency- LE (ms)	1 (5)	Very serious	Not applicable	Not serious	Serious	Not detected	No	No	NS	Very low
Wave III- Latency- RE (ms)	1 (5)	Very serious	Not applicable	Not serious	Serious	Not detected	No	No	NS	Very low
Wave III- Latency-LE (ms)	1 (5)	Very serious	Not applicable	Not serious	Serious	Not detected	No	No	NS	Very low
Wave V- Latency- RE (ms)	1 (5)	Very serious	Not applicable	Not serious	Serious	Not detected	No	Yes	-0.19 ms	Very low
Wave V- Latency-LE (ms)	1 (5)	Very serious	Not applicable	Not serious	Serious	Not detected	No	No	NS	Very low
F0 Amplitude- Transition- 65 dB SPL- Aided (µV)	1 (20)	Not serious	Not applicable	Not serious	Not serious	Not detected	RCT	Yes	-0.002	High
F0 Amplitude- Transition- 65 dB SPL- Unaided (µV)	1 (20)	Not serious	Not applicable	Serious	Not serious	Not detected	RCT	Yes	-0.001	Moderate

F0 Amplitude- Steady state- 65 dB SPL- Aided (μV)	1 (20)	Not serious	Not applicable	Not serious	Not serious	Not detected	RCT	Yes	-0.001	High
F0 Amplitude- Steay state- 65 dB SPL- Unaided (μV)	1 (20)	Not serious	Not applicable	Serious	Not serious	Not detected	RCT	Yes	-0.001	Moderate
Wave I- Amplitude (nV)	1 (5)	Very serious	Not applicable	Not serious	Serious	Not detected	No	NS	NS	Very low
Wave III- Amplitude (nV)	1 (5)	Very serious	Not applicable	Not serious	Serious	Not detected	No	NS	NS	Very low
Wave V- Amplitude (nV)	1 (5)	Very serious	Not applicable	Not serious	Serious	Not detected	No	NS	NS	Very low

Quantitative assessment of study results

Overall quantitative assessment of study results

Eleven out of the 14 included studies reported a significant acclimatization effect on at least one outcome measure (Dawes & Munro, 2016; Habicht et al., 2018; Laperuta & Fiorini, 2012; Lavie et al., 2013; Petry et al., 2010; Philibert et al., 2005; Pinheiro et al., 2012; Reber & Kompis, 2005; Stecker et al., 2006; Vestergaard, 2006; Yund et al., 2006). Conversely, three studies did not report an auditory acclimatization effect (Dawes et al., 2014; Petry et al., 2010; Saunders & Cienkowski, 1997).

Behavioural outcomes: A wide variety of behavioural measures were used to quantify the acclimatization effect. Many of the outcome measures used did not show a significant change in performance as a function of time (see Table 2). Significant improvements (ranging from 0 to 32 %) were observed on speech recognition tasks administered in quiet. In one study an improvement as large as 32% was observed. In that study the outcome consisted of a monosyllable word-recognition test administered in quiet at a level of 50 dB SPL (Reber & Kompis, 2005).

Changes in speech recognition performance in noise as measured by percent correct answers ranged from non-significant to 2.9%. Level of presentation and SNR do not seem to influence the range of improvement. Improvement on a speech recognition in noise performance as measured by the SNR level for a fixed performance ranged from non-significant to 0.9 dB. It should be noted that the results reported by Dawes and Munro (2016) based on a reduced set of data (PTA ≥ 40 dB HL and at least 6 hours per day of HA use) showed a change of 3.3 dB SNR on the SIN. This result does not appear in Table 2 because it was obtained from a stratified sample of participants. However, the result obtained with this stratified sample of participants were included in the meta-analysis section reported below.

Other auditory abilities such as performance on a dichotic listening task were used to assess acclimatization. For those tasks, most of the improvements were significant, especially for the left or non-dominant ear. The improvements ranged from 6 to 13.8% (Lavie et al., 2013; Pinheiro et al., 2012). For Difference Limen-for-Intensity (DLI) and loudness scaling tasks, most of the significant results reported were obtained when loud test stimuli were presented at frequencies above 2 kHz (Philibert et al., 2005). Specifically, significant improvements (1.1- and 1.45-dB SPL, respectively) were reported for the DLI tasks performed with test stimuli of 0.5 and 2 kHz presented at 95 dB SPL. A mean significant improvement of 5.67 dB SPL was obtained for a loudness scaling task administered with a loud and very loud test-stimulus at 2 kHz (Philibert et al., 2005).

Self-report scales: A wide variety of self-report scales were used to measure acclimatization across studies. Responses to many of the questionnaires did not show any improvements over time (e.g., subjective speech in noise, distraction questionnaire, PHAB, HAPI and the Spatial and Qualities scales of the SSQ) (Dawes & Munro, 2016; Karawani et al., 2018; Saunders & Cienkowski, 1997; Yund et al., 2006). However, a significant change in scores ranging from 5.7% to 22.8% was observed when the APHAB (sub-scales: EC, RV, BN and AV) was used (Karawani et al., 2018). In the same study, the scores for the Speech scale of the SSQ improved significantly by 15.1%.

Vestergaard (2006) used the GHABP, IOI-HA, SADL and the HAPQ to assess changes over time in new HA users. No significant changes were reported on any of the four questionnaires. Interestingly, additional analyses using a subgroup of participants who used their HAs for a minimum of 4 hrs/day showed a significant improvement of 24% and 19% on the GHABP and the IOI-HA, respectively.

Electrophysiological measures: Three studies included electrophysiological measures (Habicht et al., 2018; Karawani et al., 2018; Philibert et al., 2005). While no specific data are presented, Habicht et al. (2018) mention that no effect of HA use on magnitude and latency of event-related potentials were observed. Results from the study by Karawani et al. (2018) show a significantly shorter FFR latency as a function of time, in the aided condition, at 65 and 80 dB SPL in the new HA user group compared to the control group. Moreover, results from Karawani et al. (2018) suggest that the use of HAs decreases the amplitude of F0 for stimulus at 65 dB SPL. Finally, Philibert et al. (2005) reported a significantly shorter latency of wave V as a function of test session in the right ear as measured by ABR recordings obtained with a click presented at 90 dB HL.

Quantitative assessment (Meta-analysis) of study results

For a meta-analysis, studies must include an experimental group and a reference group (control). In the context of auditory acclimatization following HA fitting, studies compare the new HA users to a group of experienced HA users or non-HA users. Six studies included a control group which provided data that were suitable for a meta-analysis (in total there were: five behavioural outcomes, three self-reported outcomes and one electrophysiological outcome). Effect size was measured with Cohen's d equation:

$$d = \frac{(Improvement_{EG} - Improvement_{CG})}{\sqrt{({SD_{EG}}^{2} + {SD_{CG}}^{2})}/2}$$

Where: EG= experimental group and CG= Control group

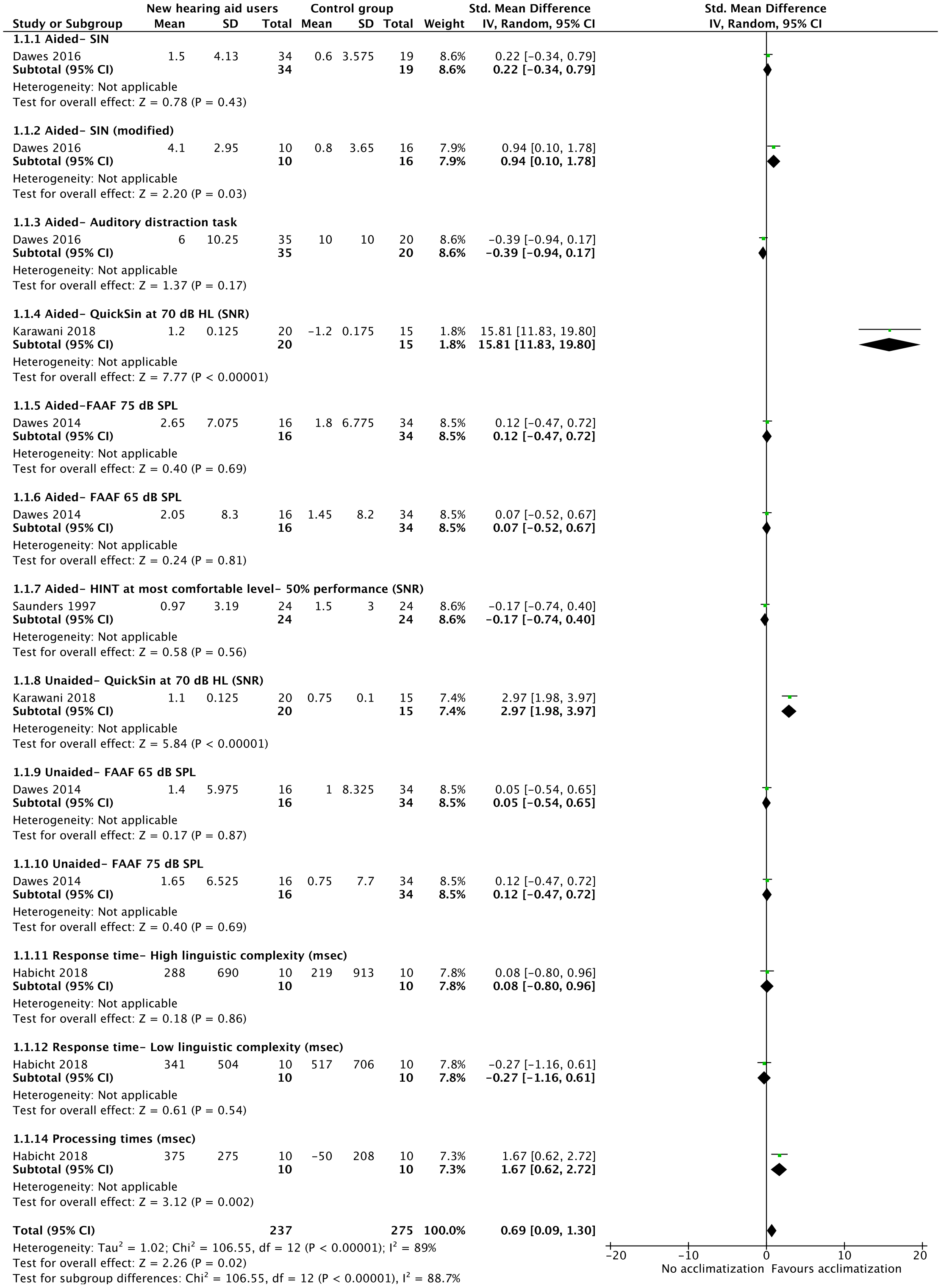
Cohen’s (1988) suggested benchmarks for evaluating ES estimates for studies using between-subjects designs. They are as follows: 0.2, 0.5 and 0.8 for small, medium and large effects, respectively. Barcikowski and Rober (1985) suggest that the benchmarks be modified when the data consists of repeated measures (within-subject design). The modified benchmarks for within-subject designs were calculated as follows:

$$d_{within} = \frac{d_{between}}{\sqrt{1 - r_{pre-post\ test}}}$$

The average pre- post-test correlation was measured for each type of outcome measure: behavioral, self-report and electrophysiological. The average pre-post test correlation for the behavioral outcomes was 0.23, resulting in within-subjects benchmarks of 0.23, 0.57 and 0.89 indicating small, medium and large effect sizes, respectively. The average pre-post test correlation for the outcomes obtained with self-report scales was 0.30, resulting in within-subjects benchmarks of 0.24, 0.6 and 0.92 indicating small, medium and large effect sizes, respectively. Finally, the pre-post test correlation for the electrophysiological outcomes was -0.06, resulting in within-subjects benchmarks of 0.21, 0.49 and 0.78 indicating small, medium and large effect sizes. It should be noted that data obtained from a sub-sample of participants based on degree of HL and amount of HA use (Dawes & Munro, 2016; Vestergaard, 2006) were included in the meta-analysis (identified by “modified”).

The overall summary statistics and forest plot for behavioural, self-reported and electrophysiological outcomes are summarized in Tables 5, 6, 7 and 8, respectively. Because of the differences in the scales of measurements between latency and amplitude data, the electrophysiological outcome measures were analysed separately.

Table 4.5. Data and Forest plot for behavioral outcomes (only studies including control group).



Study or Subgroup	New hearing aid users			Control group				Std. Mean Difference
	Mean	SD	Total	Mean	SD	Total	Weight	IV, Random, 95% CI
1.1.1 Aided- SIN								
Dawes 2016	1.5	4.13	34	0.6	3.575	19	8.6%	0.22 [−0.34, 0.79]
Subtotal (95% CI)			**34**			**19**	**8.6%**	**0.22 [−0.34, 0.79]**
Heterogeneity: Not applicable								
Test for overall effect: Z = 0.78 (P = 0.43)								
1.1.2 Aided- SIN (modified)								
Dawes 2016	4.1	2.95	10	0.8	3.65	16	7.9%	0.94 [0.10, 1.78]
Subtotal (95% CI)			**10**			**16**	**7.9%**	**0.94 [0.10, 1.78]**
Heterogeneity: Not applicable								
Test for overall effect: Z = 2.20 (P = 0.03)								
1.1.3 Aided- Auditory distraction task								
Dawes 2016	6	10.25	35	10	10	20	8.6%	−0.39 [−0.94, 0.17]
Subtotal (95% CI)			**35**			**20**	**8.6%**	**−0.39 [−0.94, 0.17]**
Heterogeneity: Not applicable								
Test for overall effect: Z = 1.37 (P = 0.17)								
1.1.4 Aided- QuickSin at 70 dB HL (SNR)								
Karawani 2018	1.2	0.125	20	−1.2	0.175	15	1.8%	15.81 [11.83, 19.80]
Subtotal (95% CI)			**20**			**15**	**1.8%**	**15.81 [11.83, 19.80]**
Heterogeneity: Not applicable								
Test for overall effect: Z = 7.77 (P < 0.00001)								
1.1.5 Aided-FAAF 75 dB SPL								
Dawes 2014	2.65	7.075	16	1.8	6.775	34	8.5%	0.12 [−0.47, 0.72]
Subtotal (95% CI)			**16**			**34**	**8.5%**	**0.12 [−0.47, 0.72]**
Heterogeneity: Not applicable								
Test for overall effect: Z = 0.40 (P = 0.69)								
1.1.6 Aided- FAAF 65 dB SPL								
Dawes 2014	2.05	8.3	16	1.45	8.2	34	8.5%	0.07 [−0.52, 0.67]
Subtotal (95% CI)			**16**			**34**	**8.5%**	**0.07 [−0.52, 0.67]**
Heterogeneity: Not applicable								
Test for overall effect: Z = 0.24 (P = 0.81)								
1.1.7 Aided- HINT at most comfortable level- 50% performance (SNR)								
Saunders 1997	0.97	3.19	24	1.5	3	24	8.6%	−0.17 [−0.74, 0.40]
Subtotal (95% CI)			**24**			**24**	**8.6%**	**−0.17 [−0.74, 0.40]**
Heterogeneity: Not applicable								
Test for overall effect: Z = 0.58 (P = 0.56)								
1.1.8 Unaided- QuickSin at 70 dB HL (SNR)								
Karawani 2018	1.1	0.125	20	0.75	0.1	15	7.4%	2.97 [1.98, 3.97]
Subtotal (95% CI)			**20**			**15**	**7.4%**	**2.97 [1.98, 3.97]**
Heterogeneity: Not applicable								
Test for overall effect: Z = 5.84 (P < 0.00001)								
1.1.9 Unaided- FAAF 65 dB SPL								
Dawes 2014	1.4	5.975	16	1	8.325	34	8.5%	0.05 [−0.54, 0.65]
Subtotal (95% CI)			**16**			**34**	**8.5%**	**0.05 [−0.54, 0.65]**
Heterogeneity: Not applicable								
Test for overall effect: Z = 0.17 (P = 0.87)								
1.1.10 Unaided- FAAF 75 dB SPL								
Dawes 2014	1.65	6.525	16	0.75	7.7	34	8.5%	0.12 [−0.47, 0.72]
Subtotal (95% CI)			**16**			**34**	**8.5%**	**0.12 [−0.47, 0.72]**
Heterogeneity: Not applicable								
Test for overall effect: Z = 0.40 (P = 0.69)								
1.1.11 Response time- High linguistic complexity (msec)								
Habicht 2018	288	690	10	219	913	10	7.8%	0.08 [−0.80, 0.96]
Subtotal (95% CI)			**10**			**10**	**7.8%**	**0.08 [−0.80, 0.96]**
Heterogeneity: Not applicable								
Test for overall effect: Z = 0.18 (P = 0.86)								
1.1.12 Response time- Low linguistic complexity (msec)								
Habicht 2018	341	504	10	517	706	10	7.8%	−0.27 [−1.16, 0.61]
Subtotal (95% CI)			**10**			**10**	**7.8%**	**−0.27 [−1.16, 0.61]**
Heterogeneity: Not applicable								
Test for overall effect: Z = 0.61 (P = 0.54)								
1.1.14 Processing times (msec)								
Habicht 2018	375	275	10	−50	208	10	7.3%	1.67 [0.62, 2.72]
Subtotal (95% CI)			**10**			**10**	**7.3%**	**1.67 [0.62, 2.72]**
Heterogeneity: Not applicable								
Test for overall effect: Z = 3.12 (P = 0.002)								
Total (95% CI)			**237**			**275**	**100.0%**	**0.69 [0.09, 1.30]**
Heterogeneity: Tau² = 1.02; Chi² = 106.55, df = 12 (P < 0.00001); I² = 89%								
Test for overall effect: Z = 2.26 (P = 0.02)								
Test for subgroup differences: Chi² = 106.55, df = 12 (P < 0.00001), I² = 88.7%								

Table 4.6. Data and Forest plot for self-reported outcomes (only studies including control group).

Study or Subgroup	New hearing aid users Mean	SD	Total	Control group Mean	SD	Total	Weight	Mean Difference IV, Fixed, 95% CI
1.2.1 GHABP (Modified)								
Vestergaard 2006	6	12	20	−18	15	5	0.2%	24.00 [9.84, 38.16]
Subtotal (95% CI)			**20**			**5**	**0.2%**	**24.00 [9.84, 38.16]**
Heterogeneity: Not applicable								
Test for overall effect: Z = 3.32 (P = 0.0009)								
1.2.2 GHABP								
Vestergaard 2006	−3	12	20	−7	24	5	0.1%	4.00 [−17.68, 25.68]
Subtotal (95% CI)			**20**			**5**	**0.1%**	**4.00 [−17.68, 25.68]**
Heterogeneity: Not applicable								
Test for overall effect: Z = 0.36 (P = 0.72)								
1.2.3 IOI−HA (Modified)								
Vestergaard 2006	12	12	20	−7	10	5	0.3%	19.00 [8.78, 29.22]
Subtotal (95% CI)			**20**			**5**	**0.3%**	**19.00 [8.78, 29.22]**
Heterogeneity: Not applicable								
Test for overall effect: Z = 3.64 (P = 0.0003)								
1.2.4 IOI−HA								
Vestergaard 2006	7	11	20	−5	19	5	0.1%	12.00 [−5.34, 29.34]
Subtotal (95% CI)			**20**			**5**	**0.1%**	**12.00 [−5.34, 29.34]**
Heterogeneity: Not applicable								
Test for overall effect: Z = 1.36 (P = 0.17)								
1.2.5 HAPQ (Modified)								
Vestergaard 2006	4	9	20	−1	9	5	0.4%	5.00 [−3.82, 13.82]
Subtotal (95% CI)			**20**			**5**	**0.4%**	**5.00 [−3.82, 13.82]**
Heterogeneity: Not applicable								
Test for overall effect: Z = 1.11 (P = 0.27)								
1.2.6 HAPQ								
Vestergaard 2006	3	8	20	1	16	5	0.1%	2.00 [−12.46, 16.46]
Subtotal (95% CI)			**20**			**5**	**0.1%**	**2.00 [−12.46, 16.46]**
Heterogeneity: Not applicable								
Test for overall effect: Z = 0.27 (P = 0.79)								
1.2.7 SADL (Modified)								
Vestergaard 2006	10	8	20	−2	10	5	0.3%	12.00 [2.56, 21.44]
Subtotal (95% CI)			**20**			**5**	**0.3%**	**12.00 [2.56, 21.44]**
Heterogeneity: Not applicable								
Test for overall effect: Z = 2.49 (P = 0.01)								
1.2.10 SADL								
Vestergaard 2006	6	8	20	1	14	5	0.2%	5.00 [−7.76, 17.76]
Subtotal (95% CI)			**20**			**5**	**0.2%**	**5.00 [−7.76, 17.76]**
Heterogeneity: Not applicable								
Test for overall effect: Z = 0.77 (P = 0.44)								
1.2.12 SSQ Speech								
Karawani 2018	1.3	1.8	20	−0.21	1.85	15	20.7%	1.51 [0.29, 2.73]
Subtotal (95% CI)			**20**			**15**	**20.7%**	**1.51 [0.29, 2.73]**
Heterogeneity: Not applicable								
Test for overall effect: Z = 2.42 (P = 0.02)								
1.2.15 SSQ Spatial								
Karawani 2018	0.11	1.85	20	−0.39	1.5	15	25.1%	0.50 [−0.61, 1.61]
Subtotal (95% CI)			**20**			**15**	**25.1%**	**0.50 [−0.61, 1.61]**
Heterogeneity: Not applicable								
Test for overall effect: Z = 0.88 (P = 0.38)								
1.2.17 SSQ Qualities								
Karawani 2018	0.4	1.35	20	0.11	1.35	15	37.9%	0.29 [−0.61, 1.19]
Subtotal (95% CI)			**20**			**15**	**37.9%**	**0.29 [−0.61, 1.19]**
Heterogeneity: Not applicable								
Test for overall effect: Z = 0.63 (P = 0.53)								
1.2.18 Auditory distraction quesitonnaire								
Dawes 2016	1.8	2.75	35	−0.7	2.6	20	14.6%	2.50 [1.04, 3.96]
Subtotal (95% CI)			**35**			**20**	**14.6%**	**2.50 [1.04, 3.96]**
Heterogeneity: Not applicable								
Test for overall effect: Z = 3.36 (P = 0.0008)								
Total (95% CI)			**255**			**105**	**100.0%**	**1.09 [0.54, 1.65]**
Heterogeneity: Chi^2 = 37.83, df = 11 (P < 0.0001); I^2 = 71%								
Test for overall effect: Z = 3.85 (P = 0.0001)								
Test for subgroup differences: Chi^2 = 37.83, df = 11 (P < 0.0001), I^2 = 70.9%								

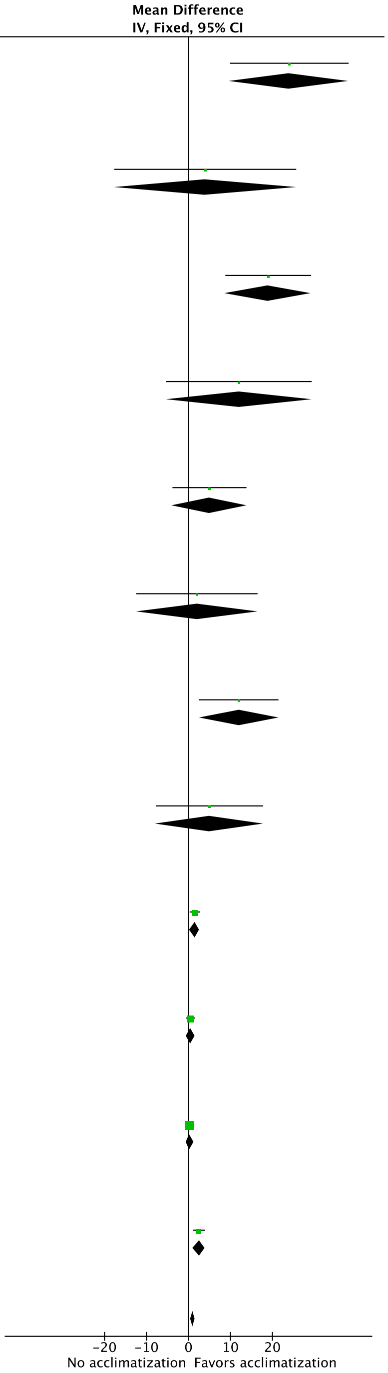


Table 4.7. Data and Forest plot for electrophysiological outcomes as measured by latency (only studies including control group).

	New hearing aid users			Control group				Mean Difference
Study or Subgroup	Mean	SD	Total	Mean	SD	Total	Weight	IV, Fixed, 95% CI
1.4.1 Latency-FFR- 65 dB SPL- Aided (ms)								
Karawani 2018	0	0.965	20	−0.61	0.755	15	21.4%	0.61 [0.04, 1.18]
Subtotal (95% CI)			**20**			**15**	**21.4%**	**0.61 [0.04, 1.18]**
Heterogeneity: Not applicable								
Test for overall effect: Z = 2.10 (P = 0.04)								
1.4.2 Latency-FFR- 65 dB SPL- Unaided (ms)								
Karawani 2018	0.3	1.055	20	0.49	0.98	15	15.1%	−0.19 [−0.87, 0.49]
Subtotal (95% CI)			**20**			**15**	**15.1%**	**−0.19 [−0.87, 0.49]**
Heterogeneity: Not applicable								
Test for overall effect: Z = 0.55 (P = 0.58)								
1.4.3 Latency-FFR- 80 dB SPL- Aided (ms)								
Karawani 2018	−0.04	1.005	20	−0.24	0.9	15	17.3%	0.20 [−0.43, 0.83]
Subtotal (95% CI)			**20**			**15**	**17.3%**	**0.20 [−0.43, 0.83]**
Heterogeneity: Not applicable								
Test for overall effect: Z = 0.62 (P = 0.54)								
1.4.4 Latency-FFR- 80 dB SPL- Unaided (ms)								
Karawani 2018	0.19	0.72	20	−0.75	1.145	15	16.0%	0.94 [0.28, 1.60]
Subtotal (95% CI)			**20**			**15**	**16.0%**	**0.94 [0.28, 1.60]**
Heterogeneity: Not applicable								
Test for overall effect: Z = 2.79 (P = 0.005)								
1.4.5 Latency-FFR- Noise- Aided (ms)								
Karawani 2018	−0.01	0.82	20	−0.56	0.925	15	20.0%	0.55 [−0.04, 1.14]
Subtotal (95% CI)			**20**			**15**	**20.0%**	**0.55 [−0.04, 1.14]**
Heterogeneity: Not applicable								
Test for overall effect: Z = 1.83 (P = 0.07)								
1.4.6 Latency-FFR- Noise- Unaided (ms)								
Karawani 2018	0.07	1.035	20	0.52	1.375	15	10.1%	−0.45 [−1.28, 0.38]
Subtotal (95% CI)			**20**			**15**	**10.1%**	**−0.45 [−1.28, 0.38]**
Heterogeneity: Not applicable								
Test for overall effect: Z = 1.06 (P = 0.29)								
Total (95% CI)			**120**			**90**	**100.0%**	**0.35 [0.09, 0.62]**
Heterogeneity: Chi² = 10.53, df = 5 (P = 0.06); I² = 53%								
Test for overall effect: Z = 2.61 (P = 0.009)								
Test for subgroup differences: Chi² = 10.53, df = 5 (P = 0.06), I² = 52.5%								

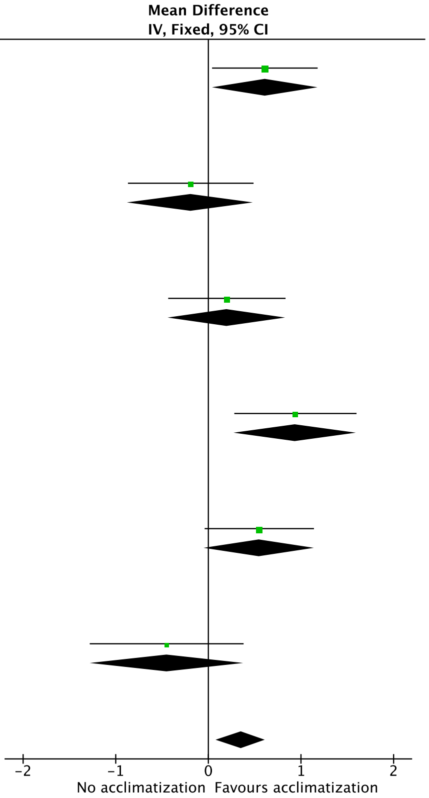
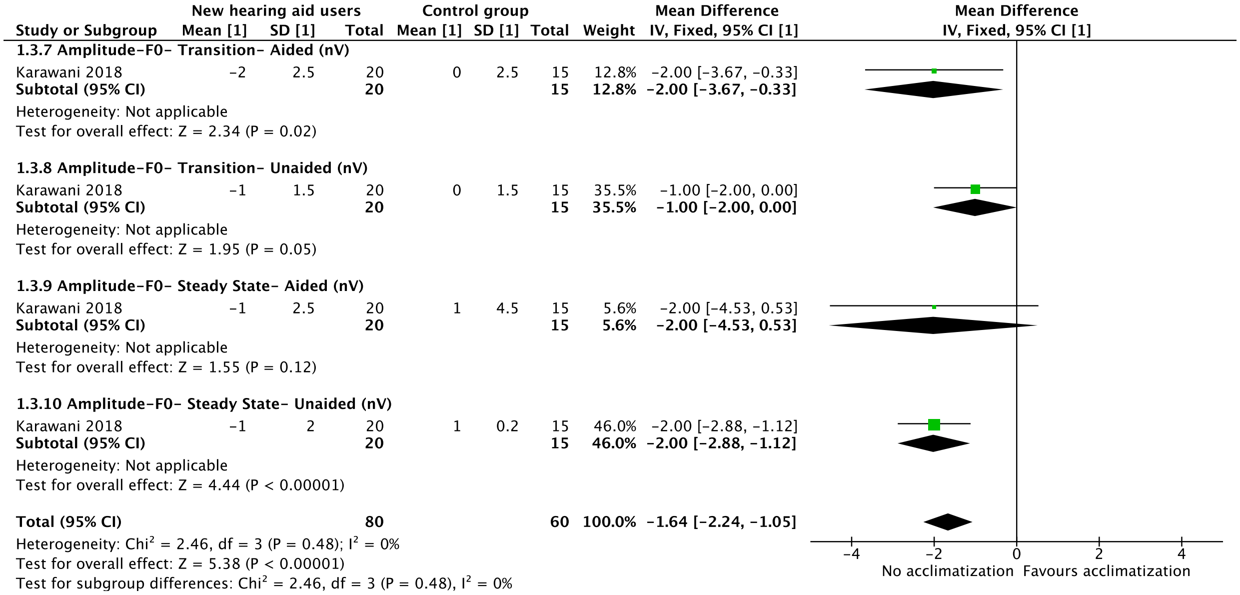


Table 4.8. Data and Forest plot for electrophysiological outcomes as measured by peak amplitude (only studies including control group).



	New hearing aid users			Control group				Mean Difference
Study or Subgroup	**Mean [1]**	**SD [1]**	**Total**	**Mean [1]**	**SD [1]**	**Total**	**Weight**	**IV, Fixed, 95% CI [1]**
1.3.7 Amplitude-F0- Transition- Aided (nV)								
Karawani 2018	-2	2.5	20	0	2.5	15	12.8%	-2.00 [-3.67, -0.33]
Subtotal (95% CI)			**20**			**15**	**12.8%**	**-2.00 [-3.67, -0.33]**
Heterogeneity: Not applicable								
Test for overall effect: Z = 2.34 (P = 0.02)								
1.3.8 Amplitude-F0- Transition- Unaided (nV)								
Karawani 2018	-1	1.5	20	0	1.5	15	35.5%	-1.00 [-2.00, 0.00]
Subtotal (95% CI)			**20**			**15**	**35.5%**	**-1.00 [-2.00, 0.00]**
Heterogeneity: Not applicable								
Test for overall effect: Z = 1.95 (P = 0.05)								
1.3.9 Amplitude-F0- Steady State- Aided (nV)								
Karawani 2018	-1	2.5	20	1	4.5	15	5.6%	-2.00 [-4.53, 0.53]
Subtotal (95% CI)			**20**			**15**	**5.6%**	**-2.00 [-4.53, 0.53]**
Heterogeneity: Not applicable								
Test for overall effect: Z = 1.55 (P = 0.12)								
1.3.10 Amplitude-F0- Steady State- Unaided (nV)								
Karawani 2018	-1	2	20	1	0.2	15	46.0%	-2.00 [-2.88, -1.12]
Subtotal (95% CI)			**20**			**15**	**46.0%**	**-2.00 [-2.88, -1.12]**
Heterogeneity: Not applicable								
Test for overall effect: Z = 4.44 (P < 0.00001)								
Total (95% CI)			**80**			**60**	**100.0%**	**-1.64 [-2.24, -1.05]**
Heterogeneity: Chi^2 = 2.46, df = 3 (P = 0.48); I^2 = 0%								
Test for overall effect: Z = 5.38 (P < 0.00001)								
Test for subgroup differences: Chi^2 = 2.46, df = 3 (P = 0.48), I^2 = 0%								

For the behavioural measures, a medium ES of 0.69 (95% CI=0.09-1.30) was obtained in favor of an acclimatization effect. The medium ES reflects evidence that an improvement in auditory abilities occurs following bilateral amplification (mainly for speech recognition in noise and in quiet, dichotic listening and processing time). It should be noted that the dependent variables that failed to demonstrate an acclimatization effect included: an auditory distraction task (Dawes & Munro, 2016), the HINT at a comfortable listening level (Saunders & Cienkowski, 1997) and the response time data for a task that consisted of processing low linguistic context sentences (Habicht et al., 2018). The meta-analysis based on the results of self-report scales revealed a large ES of 1.09 (95% CI= 0.54 – 1.65) in favor of self-report measures of acclimatization following HA fitting. The latency measures obtained from the electrophysiological tests revealed a small ES of 0.35 (95% CI=0.09 – 0.62) in favor of acclimatization. Considering the hypothesis that an acclimatization effect would lead to an increase in wave amplitude, as proposed by many authors, results obtained from electrophysiological tests revealed a large ES of 1.64 (95% CI= -2.24- -1.05) in favor of no acclimatization effect (Karawani et al., 2018).

Discussion

The present systematic review validated evidence supporting the existence of an acclimatization effect following bilateral HA fitting in adults and older adults. The most noticeable acclimatization effects were obtained with data from self-report scales. Results from the meta-analysis show a large ES and are consistent with an acclimatization effect observed with the SADL, the speech subcategory of the SSQ and all subscales of the APHAB. Overall, improvements on self-report questionnaires are related to self-perceived improvement in ease of communication, in speech understanding in quiet and in noise as well as reduced aversiveness to background noise.

Based on the behavioral data, the existence of an acclimatization effect was confirmed. Improvements in speech recognition in quiet was greater when the stimuli were presented at a low level (50 dB SPL) rather than at high presentation level (≥65 dB SPL). It is possible that at higher levels, a ceiling effect is reached (Turner & Bentler, 1998). Further an acclimatization effect was measured when the dependent variables consisted of performance on speech in noise tasks, dichotic listening tasks especially in the non-dominant ear, on a DLI task at 0.5 and 2 kHz for very loud stimuli (95 dB SPL) and on a loudness scaling task at 2 kHz for loud and very loud stimuli. Generally, acclimatization data obtained using behavioral tasks are consistent with results obtained using self-report scales. It would appear that the results of laboratory studies agree with the perception of everyday life experiences observed by new hearing aid users.

Out of the three studies in which the dependent variable consisted of a peak latency response, only the investigation by Philibert et al. (2005) support the presence of an acclimatization effect. The investigators showed that exposure to new acoustic cues shortens latency of Wave V, especially in the right ear. On the other hand, results from Karawani et al. (2018) support the theory that HA use delays the onset of auditory deprivation rather than bring about HA acclimatization. The authors suggest that the results can be interpreted as a neural synchronization following acoustic stimulation. Habicht et al. (2018) did not find any acclimatization effect when either wave amplitude or the response latency was analyzed. The discrepancy between these two studies could be explained by the absence of a control group in the study from Philibert et al. (2005). Consequently, it is impossible to ascertain whether a deprivation effect would have been observed in a group of experienced HA users as shown by Karawani et al. (2018).

Karawani et al. (2018) reported that a significant reduction in the amplitude of the fundamental frequency was observed only in the group of new HA users. This result is different from those of Habicht et al. (2018) and Philibert et al. (2005) who did not detect a change in amplitude following HA fitting. More research is needed to fully explain the reorganization of the neural pathways that may take place following HA fitting.

The behavioral, self-report and electrophysiological data analyzed suggest that there truly is a HA acclimatization effect. However, the present review does not make it possible to clearly ascertain the time course nor the magnitude of the acclimatization effect. The wide variety of outcome measures employed and the differences in time lapse between initial and follow-up measurements that were used across the studies makes it difficult to establish the specific time-course of acclimatization. For example, Reber and Kompis (2005) measured unaided and aided word recognition in quiet and in noise on three different occasions: the day of the initial fitting, 2 weeks and 6 months post HA fitting. A significant improvement in speech recognition was observed only after 6 months of HA use. In another study using a speech recognition task in noise, Dawes and Munro (2016) found a significant acclimatization effect after 1 month of HA use. All the other studies that reported a significant acclimatization effect used a retest time lapse that exceeded 1 month. An analysis of the data available reveals that the shortest possible time-course of acclimatization would be between 2 weeks and 1-month post HA fitting. More studies using a shorter time lapse between test sessions, especially immediately after the HA fitting is required to accurately describe the time-course of acclimatization to HAs.

The large variety of outcome measures in previous studies makes it difficult to clearly describe the magnitude of the acclimatization effect. Based on the results of the studies included in the present review, if a behavioral task is used to quantify the magnitude of the acclimatization effect, the results of speech recognition in noise tasks may provide sensitive data. For example, Dawes & Munro (2016) reported changes in SNR of 1 to 3 dB for a speech in noise task in which the testing algorithm used yielded a constant performance level of 50% correct across test sessions. This type of testing paradigm produces reliable results (Killion, Niquette, Gudmundsen, Revit, & Banerjee, 2004; Nilsson, Soli, & Sullivan, 1994). Moreover, depending on the slope of the psychometric function, this magnitude of change in SNR may represent an improvement in performance of as much as 10 to 30 percentage points (Taylor & Mueller, 2016).

One factor that seems very important to demonstrate an acclimatization effect is the amount of HA use. Two studies reported a significant acclimatization effect using a subgroup of participants who used their HAs at least 4 hours per day (Dawes & Munro, 2016; Vestergaard, 2006). Moreover, studies with the most important effect size had either an inclusion criterion of at least 6 hrs per day of HA use or stipulated that HAs had to be used at least 6 hrs per day (Dawes & Munro, 2016; Habicht et al., 2018; Karawani et al., 2018). Based on these results it would appear that using HAs at least 4 to 6 hrs a day provides the user with sufficient benefits to generate a significant acclimatization effect.

Limits of the included studies

The general scientific quality of the studies included in the review was graded as being low to very low. The main reasons for attributing a low grade were: downgrading the quality due to the absence of a control group, no objective measures of HA use, outcome measures with unknown psychometric properties, small sample size, failure to perform (or report) the use of an electroacoustic procedure (e.g., REIG) to evaluate the accuracy of the HA fitting.

Eight out of the 14 studies did not include a control group (Laperuta & Fiorini, 2012; Lavie et al., 2013; Petry et al., 2010; Philibert et al., 2005; Pinheiro et al., 2012; Reber & Kompis, 2005; Stecker et al., 2006; Yund et al., 2006). All of these studies reported an improvement in HA use after the initial fitting. However, because no control group were included in these studies it is impossible to eliminate a possible carry-over effect due to procedural learning. Moreover, eight of the included studies did not include an objective measure of HA use.

Five studies of the 14 studies reviewed did not report the type of signal processing incorporated in the HAs (Laperuta & Fiorini, 2012; Petry et al., 2010; Philibert et al., 2005; Pinheiro et al., 2012; Saunders & Cienkowski, 1997). The lack of information concerning this variable did not make it possible to analyze whether the type of signal processing has an effect on acclimatization to HAs. Moreover, three studies used non-standardized tests to measure acclimatization (Dawes & Munro, 2016; Philibert et al., 2005; Saunders & Cienkowski, 1997). The inclusion of non-standardized tests makes it impossible to cross-reference the results with the findings from other investigators.

In order to improve the scientific quality and the usefulness of the research reported on auditory acclimatization, future studies should include an objective measure of HA use, a control group, an a priori power analyses to determine the appropriate sample size based on the outcome measure used and report a full description of the HAs used in the study (make, model, prescriptive formula used for fitting, technology incorporated into the HAs). Also, future studies should report measures of REIG and use standardized tests or tasks with known and acceptable psychometric properties as outcome measures to quantify auditory acclimatization.

Limits of this study

The wide variety of the outcome measures used across studies made it difficult to pool together the results of different studies. The discrepancies among the dependent variables include but are not limited to the type of behavioural measures employed, the speech material used and the presentation level of the test stimuli. The authors of the present systematic review recognize that pooling together such a wide variety of outcomes is not optimal. Future scoping reviews on specific types of outcomes (e.g. behavioral measures) may add information on acclimatization related to specific auditory abilities (e.g. speech recognition in noise performance).

The GRADE evaluation framework was used to appraise the quality of the studies included in the review. This led to an overall rating of the quality of evidence as being poor and very poor. The use of GRADE may not be the most appropriate system to assess the quality of evidence in audiological research because randomized clinical trials are seldom used which automatically reduces the quality of evidence to a maximum rating of moderate. Moreover, one may question the use of this type of experimental design when investigating acclimatization to HAs. A priori the characteristics of the experimental group and the control group differ. Whereas experienced HA users are sought for the control group new HA users are recruited for the experimental group. Thus, complete randomization of those two groups is not possible. Notwithstanding these limitations, the decision was made to use a systematic and validated approach to assess the quality of the evidence available. Using the GRADE evaluation system provided a more complete and exhaustive assessment of the current quality of evidence with regards to acclimatization to HAs. Specifically, the studies were assessed on each of the following criteria: limitations, inconsistency, indirectness, imprecision, publication bias and particular strengths.

Finally, it should be noted that even though the overall quality of the articles included in the review was judged to be low to very low, a significant acclimatization effect was reported in 11 of the 14 studies incorporated in the review. Moreover, 4 of the 6 studies in which a control group was used reported a significant acclimatization effect. The consistency of the results obtained across studies and the relatively high proportion of studies in which an acclimatization effect was reported supports the conclusion that an acclimatization truly exists.

Clinical implications

Only 20% of people with HL that would benefit from HAs acquire them (Hartley, Rochtchina, Newall, Golding, & Mitchell, 2010). Moreover, even when HAs are obtained, approximately 12 to 50% of the owners do not use them (Gianopoulos, Stephens, & Davis, 2002; Lupsakko, Kautiainen, & Sulkava, 2005; Oberg, Marcusson, Nagga, & Wressle, 2012). In a review of reasons for not using HAs McCormack and Fortnum (2013) reported that low HA value was given as an explanation by people who owned HAs but did not use them. The most common factor influencing HA value is poor performance in the presence of background noise (McCormack & Fortnum, 2013). However, as evidenced by the results of this systematic review, an adjustment period takes is required after the initial HA fitting. It may take some time before a new HA user fully benefits from amplification.

For these individuals providing evidence-based information on the existence of an acclimatization effect may be critical. Specifically, this information may entice new users to persist using their HAs for a longer time period before deciding whether or not to keep the aids. The results of the present review provide audiologists with evidence that can be discussed with clients who are considering abandoning using their new hearing aids before the end of the trial period. Also, some of the factors that may contribute to optimizing the benefits provided by HAs have been identified. For example, the consistent use of the HAs for at least 4 – 6 hours per day is important in order to ensure an optimal acclimatization effect.

Conclusion

The results of this systematic review support the existence of an acclimatization effect following bilateral HA fitting among younger and older adults. Improvements in aided speech recognition in quiet and in noise and in self-reported benefits with HAs as well as triggering the neural reorganization that takes place within the first month post fitting. This evidence informs audiologists and individuals with HL who are considering HAs that it takes time to fully optimize the benefits provided by the new auditory cues provided by these devices. Degree of HL and HA use influence the magnitude of the acclimatization effect. Audiologists can use this evidence-based information to counsel their clients that in order to fully benefit from their HAs it is important for them to use their devices at least 4 to 6 hours per day during the first few weeks following the initial fitting. However, the quality of the studies included in this review was judged to be poor. To further support the existence of an acclimatization effect it is recommended that future research on this topic include objective measures of HA use (e.g. datalogging), a control group of experienced HA users and use standardized tests with known psychometric properties.

References

Arkis, P., & Burkey, J. (1994). What WRS's say about client performance, adjustment to hearing aids. Word recognition scores: Do they support adaptation. *Hearing Instruments, 45*(1), 24-25.

Arlinger, S. (2003). Negative consequences of uncorrected hearing loss--a review. *International Journal of Audiology, 42 Suppl 2,* 2S17-20. Retrieved from https://www.ncbi.nlm.nih.gov/pubmed/12918624

Arlinger, S., Gatehouse, S., Bentler, R. A., Byrne, D., Cox, R. M., Dirks, D. D., . . . Willott, J. F. (1996). Report of the Eriksholm Workshop on auditory deprivation and acclimatization. *Ear and Hearing, 17*(3 Suppl), 87S-98S. doi:10.1097/00003446-199617031-00009

Barcikowski, R., & Rober, R. (1985). *Sample size selection in single group repeated measuers analysis*. Paper presented at the Annual meeting of the American educational research association, Chicago, Il.

Barker, F., Mackenzie, E., Elliott, L., Jones, S., & de Lusignan, S. (2014). Interventions to improve hearing aid use in adult auditory rehabilitation. *Cochrane Database Systematic Reviews,* (7), CD010342. doi:10.1002/14651858.CD010342.pub2

Bentler, R., Holte, L., & Turner, C. (1999). An update on the acclimatization issue. *The Hearing Journal, 52*(11), 44, 46-47. Retrieved from https://journals.lww.com/thehearingjournal/Fulltext/1999/11000/An_update_on_the_acclimatization_issue.6.aspx

Bentler, R. A. (2005). Effectiveness of directional microphones and noise reduction schemes in hearing aids: a systematic review of the evidence. *Journal of the American Academy of Audiology, 16*(7), 473-484. doi:10.3766/jaaa.16.7.7

Bentler, R. A., Niebuhr, D. P., Getta, J. P., & Anderson, C. V. (1993). Longitudinal study of hearing aid effectiveness. I: Objective measures. *Journal of Speech and Hearing Research, 36*(4), 808-819. Retrieved from https://www.ncbi.nlm.nih.gov/pubmed/8377493

Bentler, R. A., Niebuhr, D. P., Getta, J. P., & Anderson, C. V. (1993). Longitudinal study of hearing aid effectiveness. II: Subjective measures. *Journal of Speech and Hearing Research, 36*(4), 820-831. doi:10.1044/jshr.3604.820

Boisvert, I., McMahon, C. M., & Dowell, R. C. (2012). Long-term monaural auditory deprivation and bilateral cochlear implants. *Neuroreport, 23*(3), 195-199. doi:10.1097/WNR.0b013e32834fab4b

Boyle, P. J., Nunn, T. B., O'Connor, A. F., & Moore, B. C. (2013). STARR: a speech test for evaluation of the effectiveness of auditory prostheses under realistic conditions. *Ear and Hearing, 34*(2), 203-212. doi:10.1097/AUD.0b013e31826a8e82

Byrne, D., & Dirks, D. (1996). Effects of acclimatization and deprivation on non-speech auditory abilities. *Ear and Hearing, 17*(3 Suppl), 29S-37S. doi:10.1097/00003446-199617031-00004

Castiglione, A., Benatti, A., Velardita, C., Favaro, D., Padoan, E., Severi, D., . . . Martini, A. (2016). Aging, Cognitive Decline and Hearing Loss: Effects of Auditory Rehabilitation and Training with Hearing Aids and Cochlear Implants on Cognitive Function and Depression among Older Adults. *Audiology and Neurootology, 21 Suppl 1*, 21-28. doi:10.1159/000448350

Centre for Reviews and Dissemination, C. (2008). *Systematic Reviews*. Layerthorpe, UK: CRD, University of York.

Cox, R. M. (1981). Using LDLs to establish hearing aid limiting levels. *Hearing Instruments, 32*, 16-20.

Cox, R. M., & Alexander, G. C. (1992). Maturation of hearing aid benefit: objective and subjective measurements. *Ear and Hearing, 13*(3), 131-141. Retrieved from https://www.ncbi.nlm.nih.gov/pubmed/1397752

Cox, R. M., Alexander, G. C., Taylor, I. M., & Gray, G. A. (1996). Benefit acclimatization in elderly hearing aid users. *Journal of the American Academy of Audiology, 7*(6), 428-441. Retrieved from https://www.ncbi.nlm.nih.gov/pubmed/8972444

Davis, A., Smith, P., Ferguson, M., Stephens, D., & Gianopoulos, I. (2007). Acceptability, benefit and costs of early screening for hearing disability: a study of potential screening tests and models. *Health Technology Assessment, 11*(42), 1-294. doi:10.3310/hta11420

Davis, H., Hudgins, C. V., Marquis, R. J., Nichols, R. H., Peterson, G. E., Ross, D. A., & Stevens, S. S. (1946). The selection of hearing aids. *Laryngoscope, 56*, 85-115.

Dawes, P., Emsley, R., Cruickshanks, K. J., Moore, D. R., Fortnum, H., Edmondson-Jones, M., . . . Munro, K. J. (2015). Hearing loss and cognition: the role of hearing AIDS, social isolation and depression. *PLoS One, 10*(3), e0119616. doi:10.1371/journal.pone.0119616

Dawes, P., & Munro, K. J. (2016). Auditory distraction and acclimatization to hearing aids. *Ear and Hearing, 38*(2), 174-183.

Dawes, P., Munro, K. J., Kalluri, S., & Edwards, B. (2014). Acclimatization to hearing aids. *Ear and Hearing, 35*(2), 203-212. doi:10.1097/AUD.0b013e3182a8eda4

Dawes, P., Munro, K. J., Kalluri, S., & Edwards, B. (2014). Auditory acclimatization and hearing aids: late auditory evoked potentials and speech recognition following unilateral and bilateral amplification. climatization to frequency responses: evidence from monaural fitting of hearing aids. *Journal of the Acoustical Society of America, 135*(6), 3560-3569. doi:10.1121/1.4874629

Gatehouse, S. (1989). Apparent auditory deprivation effects of late onset: the role of presentation level. climatization to frequency responses: evidence from monaural fitting of hearing aids. *Journal of the Acoustical Society of America, 86*(6), 2103-2106. doi:10.1121/1.398469

Gatehouse, S. (1992). The time course and magnitude of perceptual acclimatization to frequency responses: evidence from monaural fitting of hearing aids. *Journal of the Acoustical Society of America, 92*(3), 1258-1268. Retrieved from https://www.ncbi.nlm.nih.gov/pubmed/1401514

Gatehouse, S. (1993). Role of perceptual acclimatization in the selection of frequency responses for hearing aids. *Journal of the American Academy of Audiology, 4*(5), 296-306. Retrieved from https://www.ncbi.nlm.nih.gov/pubmed/8219296

Gatehouse, S., & Robinson, K. (1995). Acclimatisation to monaural hearing aid fitting- effects on loudness functions and preliminary evidence for parallel electrophysiological behavioural effects. In B. Kollmeier (Ed.), *Psychoacoustics, speech and hearing aids* (pp. 319). Carl von Ossietzky Universität Oldenburg, Germany: World Scientific Publishing Co.

Gianopoulos, I., Stephens, D., & Davis, A. (2002). Follow up of people fitted with hearing aids after adult hearing screening: the need for support after fitting. *BMJ, 325*(7362), 471. doi:10.1136/bmj.325.7362.471

GRADE Working Group. (2013). *GRADE Handbook*.

Granberg, S., Dahlstrom, J., Moller, C., Kahari, K., & Danermark, B. (2014). The ICF Core Sets for hearing loss--researcher perspective. Part I: Systematic review of outcome measures identified in audiological research. *International Journal of Audiology, 53*(2), 65-76. doi:10.3109/14992027.2013.851799

Habicht, J., Finke, M., & Neher, T. (2018). Auditory Acclimatization to Bilateral Hearing Aids: Effects on Sentence-in-Noise Processing Times and Speech-Evoked Potentials. *Ear and Hearing, 39*(1), 161-171. doi:10.1097/AUD.0000000000000476

Hartley, D., Rochtchina, E., Newall, P., Golding, M., & Mitchell, P. (2010). Use of hearing AIDS and assistive listening devices in an older Australian population. *Journal of the American Academy of Audiology, 21*(10), 642-653. doi:10.3766/jaaa.21.10.4

Horwitz, A. (1995). *The timecourse of hearing aid benefit.* (PhD Dissertation). Graduate School of Syracuse University, New York, US.

Humes, L. E., Christensen, L., Thomas, T., Bess, F. H., Hedley-Williams, A., & Bentler, R. (1999). A comparison of the aided performance and benefit provided by a linear and a two-channel wide dynamic range compression hearing aid. *Journal of Speech Language and Hearing Research, 42*(1), 65-79. doi:10.1044/jslhr.4201.65

Humes, L. E., Halling, D., Schmitt, K., Coughlin, M., Wilson, D. L., & Kinden, S. (1995). *Longitudinal study of hearing aid use, satisfaction and benefit in a group of elderly hearing aid wearers.* Paper presented at the 1st Biennal Conference: Hearing aid Research and Development, NIDCD/DVA, Bethesda, MD.

Humes, L. E., Wilson, D. L., Barlow, N. N., & Garner, C. (2002). Changes in hearing-aid benefit following 1 or 2 years of hearing-aid use by older adults. *Journal of Speech Language and Hearing Research, 45*(4), 772-782. Retrieved from https://www.ncbi.nlm.nih.gov/pubmed/12199406

Ito, J., Sakakibara, J., Honjo, I., Iwasaki, Y., & Yonekura, Y. (1990). Positron emission tomographic study of auditory sensation in a patient with a cochlear implant. *Archives of Otolaryngology Head and Neck Surgery, 116*(12), 1437-1439. doi:10.1001/archotol.1990.01870120083015

Karawani, H., Jenkins, K. A., & Anderson, S. (2018). Neural and behavioral changes after the use of hearing aids. *Clinical Neurophysiology, 129*(6), 1254-1267. doi:10.1016/j.clinph.2018.03.024

Killion, M. C., Niquette, P. A., Gudmundsen, G. I., Revit, L. J., & Banerjee, S. (2004). Development of a quick speech-in-noise test for measuring signal-to-noise ratio loss in normal-hearing and hearing-impaired listeners. *Journal of the Acoustical Society of America, 116*(4 Pt 1), 2395-2405. doi:10.1121/1.1784440

Kraus, N., McGee, T., Carrell, T. D., King, C., Tremblay, K., & Nicol, T. (1995). Central auditory system plasticity associated with speech discrimination training. *Journal of Cognitive Neuroscience, 7*(1), 25-32. doi:10.1162/jocn.1995.7.1.25

Laperuta, E. B., & Fiorini, A. C. (2012). Satisfaction of elderly individuals with hearing aids in the first six months of use. *Journal da Sociedade Brasileira de Fonoaudiology, 24*(4), 316-321. doi:10.1590/s2179-64912012000400005

Laplante-Levesque, A., Hickson, L., & Worrall, L. (2012). What makes adults with hearing impairment take up hearing AIDS or communication programs and achieve successful outcomes? *Ear and Hearing, 33*(1), 79-93. doi:10.1097/AUD.0b013e31822c26dc

Larson, V. D., Williams, D. W., Henderson, W. G., Luethke, L. E., Beck, L. B., Noffsinger, D., . . . Rappaport, B. Z. (2000). Efficacy of 3 commonly used hearing aid circuits: A crossover trial. NIDCD/VA Hearing Aid Clinical Trial Group. *JAMA, 284*(14), 1806-1813. doi:10.1001/jama.284.14.1806

Lavie, L., Attias, J., & Karni, A. (2013). Semi-structured listening experience (listening training) in hearing aid fitting: influence on dichotic listening. *American Journal of Audiology, 22*(2), 347-350. doi:10.1044/1059-0889(2013/12-0083)

Lin, F. R., Yaffe, K., Xia, J., Xue, Q. L., Harris, T. B., Purchase-Helzner, E., . . . Health, A. B. C. S. G. (2013). Hearing loss and cognitive decline in older adults. *JAMA Internal Medicine, 173*(4), 293-299. doi:10.1001/jamainternmed.2013.1868

Lindley, G. A. (1999). Adaptation to loudness: implications for hearing aid fittings. *Hearing Journal, 52*(11), 50-57.

Lindley, G. A. t., Palmer, C. V., Durrant, J., & Pratt, S. (2000). Adaptation to loudness and environmental stimuli in three newly fitted hearing aid users. *Journal of the American Academy of Audiology, 11*(6), 316-322. Retrieved from https://www.ncbi.nlm.nih.gov/pubmed/10858003

Lunner, T., Rudner, M., & Ronnberg, J. (2009). Cognition and hearing aids. *Scandinavian Journal of Psychology, 50*(5), 395-403. doi:10.1111/j.1467-9450.2009.00742.x

Lupsakko, T. A., Kautiainen, H. J., & Sulkava, R. (2005). The non-use of hearing aids in people aged 75 years and over in the city of Kuopio in Finland. *European Archives of Otorhinolaryngology, 262*(3), 165-169. doi:10.1007/s00405-004-0789-x

Malinoff, R. L., & Weinstein, B. E. (1989). Measurement of hearing aid benefit in the elderly. *Ear and Hearing, 10*(6), 354-356. doi:10.1097/00003446-198912000-00006

McCormack, A., & Fortnum, H. (2013). Why do people fitted with hearing aids not wear them? *International Journal of Audiology, 52*(5), 360-368. doi:10.3109/14992027.2013.769066

Morgan, D. E., & Dirks, D. D. (1974). Loudness discomfort level under earphone and in the free field: the effects of calibration methods. *Journal of the Acoustical Society of America, 56*(1), 172-178. doi:10.1121/1.1903249

Mulrow, C. D., Tuley, M. R., & Aguilar, C. (1992). Sustained benefits of hearing aids. *Journal of Speech and Hearing Research, 35*(6), 1402-1405. doi:10.1044/jshr.3506.1402

Munro, K. J. (2008). Reorganization of the adult auditory system: perceptual and physiological evidence from monaural fitting of hearing AIDS. *Trends in Amplification, 12*(2), 85-102. doi:10.1177/1084713808316173

Munro, K. J., & Lutman, M. E. (2003). The effect of speech presentation level on measurement of auditory acclimatization to amplified speech. *Journal of the Acoustical Society of America, 114*(1), 484-495. Retrieved from https://www.ncbi.nlm.nih.gov/pubmed/12880059

National Council on the Aging. (1999). *The Consequences of Untreated Hearing Loss in Older Persons [Study conducted by the Seniors Research Group]*. Retrieved from Washigton, DC: US:

Nilsson, M., Soli, S. D., & Sullivan, J. A. (1994). Development of the Hearing in Noise Test for the measurement of speech reception thresholds in quiet and in noise. *Journal of the Acoustical Society of America, 95*(2), 1085-1099. doi:10.1121/1.408469

Oberg, M., Marcusson, J., Nagga, K., & Wressle, E. (2012). Hearing difficulties, uptake, and outcomes of hearing aids in people 85 years of age. *International Journal of Audiology, 51*(2), 108-115. doi:10.3109/14992027.2011.622301

Palmer, C. V., Nelson, C. T., & Lindley, G. A. t. (1998). The functionally and physiologically plastic adult auditory system. *Journal of the Acoustical Society of America, 103*(4), 1705-1721. Retrieved from https://www.ncbi.nlm.nih.gov/pubmed/9566316

Petry, T., Santos, S. N., & Costa, M. J. (2010). Speech recognition according to the length of hearing aid use. *Brazilian Journal of Otorhinolaryngology, 76*(4), 462-468. Retrieved from https://www.ncbi.nlm.nih.gov/pubmed/20835533

Philibert, B., Collet, L., Vesson, J. F., & Veuillet, E. (2005). The auditory acclimatization effect in sensorineural hearing-impaired listeners: evidence for functional plasticity. *Hearing Research, 205*(1-2), 131-142. doi:10.1016/j.heares.2005.03.013

Pinheiro, M. M., Iorio, M. C., Miranda, E. C., Dias, K. Z., & Pereira, L. D. (2012). The influence of cognitive aspects and auditory processes on the hearing aid acclimatization in the elderly. *Journal da Sociedade Brasileira de Fonoaudiollogia, 24*(4), 309-315. doi:10.1590/s2179-64912012000400004

Ponton, C. W. (1996). Possible application of functional imaging of the human auditory system in the study of acclimatization and late onset deprivation. *Ear and Hearing, 17*(3 Suppl), 78S-86S. doi:10.1097/00003446-199617031-00008

Reber, M. B., & Kompis, M. (2005). Acclimatization in first-time hearing aid users using three different fitting protocols. *Auris Nasus Larynx, 32*(4), 345-351. doi:10.1016/j.anl.2005.05.008

Robinson, K., & Summerfield, A. Q. (1996). Adult auditory learning and training. *Ear and Hearing, 17*(3 Suppl), 51S-65S. doi:10.1097/00003446-199617031-00006

Santos, S. N., Petry, T., & Costa, M. J. (2010). Acclimatization effect in speech recognition: evaluation without hearing aids. *Pro-Fono, 22*(4), 543-548. doi:10.1590/s0104-56872010000400031

Saunders, G. H., & Cienkowski, K. M. (1997). Acclimatization to hearing aids. *Ear and Hearing, 18*(2), 129-139. Retrieved from https://www.ncbi.nlm.nih.gov/pubmed/9099562

Seniors Research Group. (1999). *The consequences of untreated hearing loss in older persons*.

Silva, D. P., Silva, V. B., & Aurelio, F. S. (2013). Auditory satisfaction of patients fitted with hearing aids in the Brazilian Public Health Service and benefits offered by the hearing aids.

Brazilian Journal of Otorhinolaryngology, 79(5), 538-545. doi:10.5935/1808-8694.20130098

Simpson, A. N., Matthews, L. J., Cassarly, C., & Dubno, J. R. (2019). Time From Hearing Aid Candidacy to Hearing Aid Adoption: A Longitudinal Cohort Study. *Ear and Hearing, 40*(3), 468-476. doi:10.1097/AUD.0000000000000641

Solheim, J., & Hickson, L. (2017). Hearing aid use in the elderly as measured by datalogging and self-report. *International Journal of Audiology, 56*(7), 472-479. doi:10.1080/14992027.2017.1303201

Stecker, G. C., Bowman, G. A., Yund, E. W., Herron, T. J., Roup, C. M., & Woods, D. L. (2006). Perceptual training improves syllable identification in new and experienced hearing aid users. *Journal of Rehabilitation Research & Development, 43*(4), 537-552. doi:10.1682/jrrd.2005.11.0171

Taylor, & Mueller, G. (2016). *Fitting and dispensing hearing aids* (2nd ed.): Plural Publishing.

Taylor, K. S. (1993). Self-perceived and audiometric evaluations of hearing aid benefit in the elderly. *Ear and Hearing, 14*(6), 390-394. Retrieved from https://www.ncbi.nlm.nih.gov/pubmed/8307242

Thai-Van, H., Philibert, B., Veuillet, E., & Collet, L. (2009). Assessment of auditory plasticity using psychoacoustic and electrophysiological measurements. *Audiological Medicine, 7*(1), 55-66. doi:10.1080/16513860802638752

Turner, C. W., & Bentler, R. A. (1998). Does hearing aid benefit increase over time? *The Journal of the Acoustical Society of America, 104*(6), 3673-3674. Retrieved from https://www.ncbi.nlm.nih.gov/pubmed/9857524

Turner, C. W., Humes, L. E., Bentler, R. A., & Cox, R. M. (1996). A review of past research on changes in hearing aid benefit over time. *Ear and Hearing, 17*(3 Suppl), 14S-25S. doi:10.1097/00003446-199617031-00003

Valente, M., Fabry, D. A., & Potts, L. G. (1995). Recognition of speech in noise with hearing aids using dual microphones. *Journal of the American Academy of Audiology, 6*(6), 440-449. Retrieved from https://www.ncbi.nlm.nih.gov/pubmed/8580504

Vestergaard, M. D. (2006). Self-report outcome in new hearing-aid users: Longitudinal trends and relationships between subjective measures of benefit and satisfaction. *International Journal of Audiology, 45*(7), 382-392. doi:10.1080/14992020600690977

Walden, B. E., Schuchman, G. I., & Sedge, R. K. (1977). The reliability and validity of the comfort level method of setting hearing aid gain. *Journal of Speech and Hearing Disorder, 42*(4), 455-461. doi:10.1044/jshd.4204.455

Walker, G., Dillon, H., Buyrne, D., & Christen, R. (1984). The use of discomfort levels for selecting the maximum output of hearing aids. *Australian Journal of Audiology, 6*(1), 23-32.

Wieselberg, M. B., & Iorio, M. C. (2012). Hearing aid fitting and unilateral auditory deprivation: behavioral and electrophysiologic assessment. *Brazilian Journal of Otorhinolaryngology, 78*(6), 69-76. doi:10.5935/1808-8694.20120036

Willott, J. F. (1996). Physiological plasticity in the auditory system and its possible relevance to hearing aid use, deprivation effects, and acclimatization. *Ear Hear, 17*(3 Suppl), 66S-77S. doi:10.1097/00003446-199617031-00007

Wood, S. A., & Lutman, M. E. (2004). Relative benefits of linear analogue and advanced digital hearing aids. *Int J Audiol, 43*(3), 144-155. doi:10.1080/14992020400050020

World Health Organization, W. (2018). Deafness and hearing loss. Retrieved from https://www.who.int/news-room/fact-sheets/detail/deafness-and-hearing-loss

Yund, E. W., Roup, C. M., Simon, H. J., & Bowman, G. A. (2006). Acclimatization in wide dynamic range multichannel compression and linear amplification hearing aids. *J Rehabil Res Dev, 43*(4), 517-536. doi:10.1682/jrrd.2005.06.0099

Chapter 5- Acclimatization to hearing aids by older adults

Acclimatization to Hearing Aids by Older Adults

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Abstract

Objectives: Audiologists and hearing aid users (HAUs) generally agree that an adaptation period is needed following the first hearing aid (HA) experience. The main purpose of this study is to investigate the acclimatization of older adult listeners with hearing loss to HAs using listening effort and behavioral measures.

Design: Participants (n=47) were older adults with mild to moderately severe sensorineural hearing loss. Thirty-two participants were new HAUs and 15 participants were experienced HAUs. New HAUs were randomly assigned to one of two groups: noise reduction algorithms (NRA) and directional microphones (DM) activated or NRA and DM deactivated. Speech recognition in noise and listening effort were assessed on eight different occasions during a 10-month period. A dual-task paradigm was used to measure the listening effort deployed to recognize speech in noise. The primary task consisted of the Hearing in Noise Test (HINT) which also served as the behavioural speech in noise measure. The secondary task was a tactile pattern-recognition task in which participants had to identify a sequence of three tactile stimuli that varied in duration. The two listening effort outcomes were the proportional dual-task cost and the response time on the secondary task. Cognitive abilities, including working memory and speed of processing were evaluated using the Reading Span Test and the Digit Symbol Substitution Test, respectively.

Results: Results show a significant time*group interaction. Both groups of new HAUs showed improvement over time in speech in noise performances (change of ~2 dB signal to noise ratio) and the experienced HAUs did not improve over time. The acclimatization effect was observed over a period of 4 weeks. There was no significant change over time on both measures of listening effort. There was no association between amplitude of acclimatization and the cognitive abilities measured.

Conclusion: An acclimatization effect following HA experience was observed. Specifically, the new HAUs displayed a clinically significant change of 2 dB in signal to noise ratio on the HINT 4 weeks following their initial fitting. The acclimatization effect is not correlated to cognitive abilities.

List of abbreviations

ADAS-cog: Assessment Scale of Alzheimer’s Disease

CRIUGM : *Centre de recherche de l’Institut universitaire de gériatrie de Montréal*

dB HL: Decibel Hearing Level

dB SPL: Decibel Sound pressure level

DM : Directional microphones

DDST : Digit symbol substitution test

EHAU: Experienced hearing aid users

EM: Expectation-Maximization algorithm

FAAF: Four Alternative Auditory Feature test

FUEL: Framework for Understanding Effortful listening

HA: Hearing aid

HAU: Hearing aid users

HHIE: Hearing Handicap Inventory for the Elderly

HINT: Hearing in Noise Test

HL: Hearing loss

MMSE: Mini Mental State Examination

MoCA: Montreal Cognitive assessment

NRA: Noise reduction algorithms

OA: Older adults

pDTC: Proportional Dual-task cost

RST: Reading span test

RT: Response times

SIN: Speech recognition in noise test

SNR: Signal to noise ratio

WDRC: Wide dynamic range compression

WMC: Working memory capacity

Introduction

Hearing aids (HAs) are usually the first intervention strategy proposed to individuals with hearing loss (HL) (Barker et al. 2014). New technologies such as wide dynamic range compression (WDRC), directional microphones (DM) and noise reduction algorithms (NRA) have been incorporated into HAs. The addition of this technology reduces annoyance to noise (Brons et al. 2014; Lunner et al. 2009) and it is intended to improve the ability of HA users to understand speech under difficult listening conditions.

Over the years, acclimatization to HAs has been of interest to many researchers. Gatehouse (1989) was the first to use the term acclimatization to investigate an adaptation effect attributable to the auditory amplification provided by HAs. In the Report of the Eriksholm workshop on auditory deprivation and acclimatization, acclimatization was defined as "a systematic change in auditory performance linked to a change in acoustic information which cannot be attributed to task, procedural or training effects" (Arlinger et al. 1996, p.87S). As per the Eriksholm workshop, changes in auditory performances were limited to speech identification abilities both in quiet and in noise and performance on psychoacoustical tasks, including loudness adaptation.

Previously published scientific evidence on acclimatization is mixed. Many investigators have failed to demonstrate an auditory acclimatization effect (Dawes et al. 2014; Humes et al. 2002; Saunders & Cienkowski 1997; Taylor 1993; Turner & Bentler 1998) while others have reported the presence of such an effect (Cox & Alexander 1992; Dawes & Munro 2016; Gatehouse 1992; Munro & Lutman 2003). These inconsistencies could be explained by the fact that acclimatization is often reported with a small effect size and a large interindividual variability in performance.

Palmer et al. (1998) identified factors that vary across studies on acclimatization to HAs and which could explain the conflicting outcomes. These factors include: (1) accuracy of HA fitting in terms of audibility, (2) use of HAs (e.g. hours/day), (3) type of signal processing incorporated in the HAs, (4) age range of participants, (5) degree of HL, (6) test material used to measure acclimatization and (7) steps taken to account for procedural learning. The variability in the inclusion criteria retained to recruit participants as well as the methodology employed across studies broadens the area of research and leaves many unanswered questions (Palmer et al. 1998).

Investigators have commented on specific aspects of the auditory acclimatization effect. Gatehouse (1989) measured unaided speech identification in 24 unilaterally aided participants and compared the performance of the aided ear with the performance of the unaided ear. At high presentation levels (85 and 90 dB SPL), the results revealed better performance in the fitted ear. Contrary findings were observed at a lower presentation levels (65 dB SPL). This suggests that the effect of acclimatization to HAs could be intensity-specific and modulated by the amount of the gain provided by the devices. This effect was also demonstrated by Munro and Lutman (2003). Concerning the spectral composition of the speech stimuli, Saunders and Cienkowski (1997) mentioned that the test material used in their study was mainly sensitive to low- and mid-frequencies which could explain the absence of an acclimatization effect for participants with high-frequency HL. It seems reasonable that acclimatization would be observed only in frequency regions that provide new acoustical information to HA users.

Many investigators have also tried to define a specific time course of the acclimatization effect. Using the Four Alternative Auditory Feature test (FAAF) (Foster & Haggard 1979, 1987), Gatehouse (1992) measured improvements in speech perception performance over a 12-week period following HA fitting. Improvements of more than 15 % were observed between week 6 and week 12 post fitting. Fitting participants with linear HAs according to the NAL prescriptive formula, Gatehouse (1993) confirmed this time course by measuring an initial benefit 8 weeks following HA fitting (2.3% improvement) and a performance plateau 16 weeks post-fitting (4.4% improvement). Based on those findings it was proposed that the time course of acclimatization to HAs begins at around 6 to 8 weeks after the initial fitting and reaches a maximum effect between 12 to 16 weeks post-fitting. Using WDRC technology, Yund et al. (2006) observed a 4.6% improvement peak at 8 weeks post bilateral HA fitting. Individuals fitted with linear technology improved more quickly (2-4 weeks) but only by 2.2% (Yund et al. 2006).

Using a speech recognition task in noise, Dawes and Munro (2016) showed a significant change of 3 dB signal to noise ratio (SNR) for a subgroup of participants (PTA [puretone average] HL of more than 40 dB HL and HA use of more than 6 hours per day) after 30 days of HA use. It is noteworthy that in the studies by Dawes and Munro and Yund et al. (2006), all participants were fitted bilaterally as opposed to unilaterally as was the case in the study reported by Gatehouse (1993). A bilateral exposure to acoustic stimulation could help individuals acclimatize to the HAs. These findings suggest that the acclimatization effect following bilateral HA fitting takes place earlier than previously proposed by Gatehouse (1992, 1993). Moreover, Gatehouse did not employ a precise measurement of daily use of HAs (e.g., datalogging). This factor may have influenced the parameters of the acclimatizing effect reported.

A recent systematic review concluded that, relative to individuals with normal hearing, individuals with hearing impairment expend significantly more effort to understand speech (Ohlenforst et al. 2017). This increase in expended resources may be attributable to the increased effort required to experience successful speech understanding (McCoy et al. 2005; Ohlenforst et al. 2017; Ronnberg et al. 2013) or “the amount of processing resources allocated to a specific auditory task” (Gagné et al. 2017, p.1). Gagné et al. (2017) described a wide range of parameters in dual-task paradigm methodologies and concluded that no specific methods has proven more suitable than others to measure listening effort. Pichora-Fuller et al. (2016) developed a Framework for Understanding Effortful listening (FUEL) that explains the theoretical assumptions of the dual-task paradigm. This framework explains the relationship between cognitive demands and the supply of cognitive capacity while also taking in consideration motivation, adaptive gain control, optimal performance, fatigue and pleasure

(Pichora-Fuller et al. 2016).

There are many ways to measure listening effort such as self-report scales, behavioral and physiological measures. A complete review can be found in McGarrigle et al. (2014). A common behavioral measure of listening effort is the dual-task paradigm (Desjardins & Doherty 2013; Gagné et al. 2017). This method of measuring listening effort is considered representative of real-life situations as individuals are often asked to perform two or more tasks at the same time (Gagné et al. 2017).

The dual-task paradigm consists of performing two tasks (a primary task and a secondary task) separately as well as concurrently. The primary task typically involves a listening activity performed in quiet or in a background of noise and a secondary task that may include a memory task (Rakerd et al. 1996), a tactile pattern recognition task (TPRT) (Anderson Gosselin & Gagné 2011; Fraser et al. 2010) or a visual tracking task (Desjardins & Doherty 2014). Two dependent variables are typically used to quantify listening effort; (1) proportional dual-task cost (pDTC) and (2) response times (RT) (Gagné et al. 2017; Pals et al. 2015). For a complete review of behavioural listening effort assessment using the dual-task paradigm, see (Gagné et al. 2017). Although many investigators have used percent correct performance on speech recognition tasks to measure acclimatization to HAs, as far as it can be determined, no studies have used measures of listening effort to investigate acclimatization. Data showing that listening effort decreases as a function of time following HA fitting could be taken as a demonstration of an acclimatization effect.

Another factor that may influence acclimatization to HAs is cognitive function. Individual cognitive abilities have been associated with difficulties concerning HA amplification (Lunner et al. 2009; Pichora-Fuller & Singh 2006; Stenfelt & Ronnberg 2009). Pinheiro et al. (2012), found no correlation between the improvement on a speech recognition task following HA fitting and cognitive functions as measured by the Assessment Scale of Alzheimer’s Disease (ADAS-cog: Rosen, Mohs, & Davis, 1984) and the Mini Mental State Examination (MMSE: Folstein, Folstein, & McHugh, 1975) . It is worth noting that the reassessment of the speech perception task varied from one participant to another (from 3 to 10 months post HA fitting) and that the speech recognition task and the binaural integration task were performed without HAs (Pinheiro et al. 2012).

Self-reported hearing problems are associated with HA uptake and HA use (Knudsen et al. 2010). A questionnaire commonly used to measure hearing disability amongst older adults with HL is the Hearing Handicap Inventory for the Elderly (HHIE: Ventry & Weinstein, 1982). Humes et al. (2003) reported that HA uptake was greater among individuals who reported greater hearing disability as measured by the HHIE. As far as it can be determined, self-reported hearing impairment has not yet been reported in studies that have investigated the HA acclimatization effect. In the present study we predict that there will be a significant correlation between the amount of self-reported hearing disability and the acclimatization effect. Specifically, the acclimatization period will be shorter for individuals who report more hearing disability.

The present study was designed to address four specific goals: (1) To determine whether speech understanding in noise, measured with the Hearing in Noise Test (HINT), and listening effort, measured using a dual-task experimental paradigm, can be used to quantify the acclimatization to HAs exhibited by older adults with HL; (2) To investigate the effect of NRA and DM on hearing aid acclimatization; (3) To characterize the time course of HA acclimatization; (4) To investigate the relationship between working memory, speed of processing and reported hearing disability and the acclimatization period.

Materials and Methods

Participants

Power analyses concluded that a total sample size of 45 would provide at least 80% power with 3 groups of participants to detect a small effect size (f=0.167; based on a within-between analysis of variance with an α level of 0.05). Participants were recruited through a bank of volunteer participants at the *Centre de recherche de l'Institut universitaire de gériatrie de Montréal* (CRIUGM). Participants included 32 first-time HA users (new HAUs) ranging from

63 to 75 years of age (M=70.2, SD= 3) and 15 experienced HA users (experienced HAUs), between 61 and 76 years of age (M=71, SD=4.7). Participants in the latter group reported using HAs bilaterally on a regular basis for at least one year before their participation in the study. Five participants withdrew from the study before the final session (one did not attend the last two sessions [experienced HAU] and four did not attend the last session [new HAUs]). Among the new HAUs, the reasons for abandoning the study were: loss of HAs (n=2) and data logging of less that 6 hours per day (n=2). Among the experienced HAUs, the reason for abandoning the study was health issues (n=1). For both groups, the missing data were replaced by hypothetical outcomes using the SPSS Missing Values Analysis module. First, the Expectation-Maximization (EM) algorithm was used to generate a new value. Then, the resulting value was checked to determine whether it was within the expected values (van Buuren 2018). For RT and performance on TPRT under the single and dual-task conditions the results showed that the EM means was significant. Hence, data imputation was accomplished with series mean for these variables. For speech perception in noise performance data, the EM means were significant, and the missing values were replaced using linear trend at point.

Palmer et al. (1998) reported that an acclimatization effect was observed mostly among individuals presenting HL of at least 40-45 dB HL. In the present study, all participants had mild to moderately severe sensorineural HL, slopping in the high frequencies and displayed an impairment of at least 40 dB HL at 4 kHz (see **Figure 5.1**). For both experimental groups (new and experienced HAUs) the exclusion criteria related to HL were 1) air-bone gap >10 dB HL at any frequency between 0.5 and 4 k Hz, 2) an asymmetry in detection thresholds >15 dB HL between ears, at any audiometric frequency, and 3) abnormal middle ear function assessed using immitancemetry.

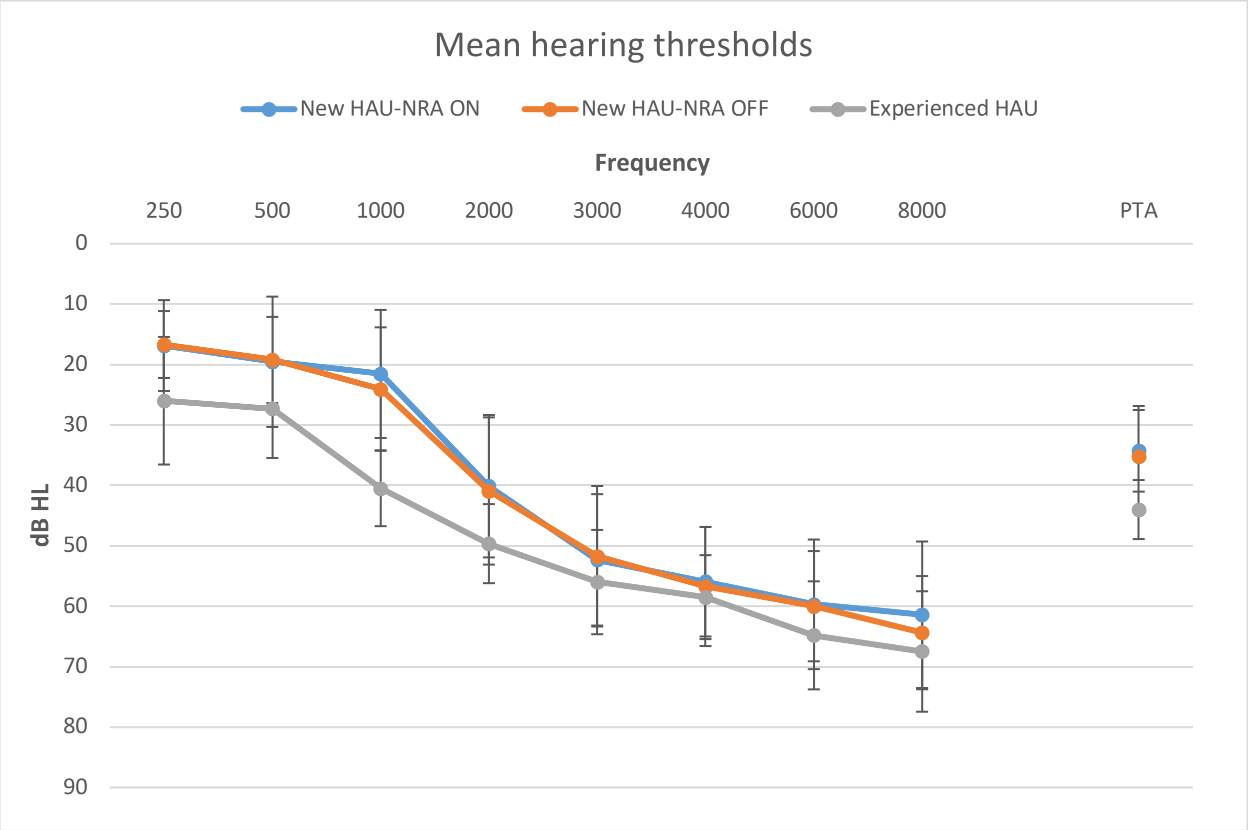

Figure 0.1. Mean hearing detection thresholds for new and experienced hearing aid users (average of thresholds for right and left ears). PTA (puretone average) represents average thresholds at 0.5, 1, 2 and 4 kHz. Error bars show ±1 standard-deviation of the mean

The hearing detection thresholds of the experienced HAUs (the control group) were significantly poorer than those of the new HAUs at 250, 500, 1000 and 2000 Hz (see **Table 5.1**). Also, mean hearing detection thresholds at 0.5, 1, 2 and 4 kHz differed significantly between groups (F[2,46]=9.384, p<0.001). While post-hoc tests using Bonferroni adjustments show no significant differences between both new HAUs groups (p=1.000), there is a significant difference of mean hearing thresholds between new HAUs-NRA ON and experienced HAUs (p=0.001) and between new HAUs-NRA OFF and experienced HAUs (p=0.003). The significant difference in hearing detection thresholds observed for the experienced HAU participants was not considered to be critical because this group served as the control group to monitor whether performance on the dependent variables would change as a function of test sessions.

Table 5.1 Means (SD; ranges) and one-way ANOVA results for biographical data of new and experienced HAUs.

New HAUs-NRA OFF	new HAUs-NRA ON	experienced HAUs	p-value
7;9	9;7	8;7	p=0.376
70.3 (3.6; 63-75)	70.1 (2.4; 65-74)	71.1 (4.7; 61-76)	p=0.720
35.2 (8.3; 22.5-48.75)	34.3 (6.7; 15.6; 43.1)	44 (4.9; 35-51.8)	p<0.001*

* Two-tailed significant p-value for one-way ANOVA

† Mean PTA (puretone average) of thresholds at 0.5, 1, 2 and 4 k Hz in dB HL

Additional inclusion criteria were that participants report that Canadian French was their first language, to be in good physical health, report no neurological disorders and no cognitive impairment. All participants obtained a score of at least 26/30 on the Montreal Cognitive Assessment (MoCA: Nasreddine et al., 2005). Based on self-report, experienced HAUs indicated that they used their HAs for at least 6 hours per day and they had a minimum of 1-year experience with HAs. New HAUs had no prior experience of HA use. They agreed to use their new HAs at least 6 hours per day as verified by datalogging.

Ethics approval was obtained by the Ethics Committee of the *CRIUGM* and informed consent was obtained for all participants.

Hearing aids

New HAUs were fitted bilaterally with receiver-in-the-ear Oticon OPN 1 (donated by Oticon for this study). At the time of the study, OPN 1 was the high-end technology level HAs from the Oticon OPN platform with 64 processing channels, bass boost streaming, 16 fitting bands and a fitting range of 120 to 9500 Hz. The volume control was deactivated for all new HAUs so that the prescription gain could not be modified. Because all participants had normal or near-normal hearing in the low-frequencies, coupling was done with open domes. One new HAU and one experienced HAU were fitted with closed domes because feedback could not be controlled with the feedback manager in software.

An open-canal fitting can generate delays in amplified high-frequency sounds compared to low-frequency sounds (Stone & Moore 1999; Stone et al. 2008) and reduce benefits from directional microphones and NRA (Winkler et al. 2016). However, satisfaction ratings and success rate is greater with open canal fittings than when a closed dome is used (Gnewikow & Moss 2006; Taylor 2006). Therefore, their use was preferable as participants were required to use their HAs for a minimum of six hours per day, even at the beginning of the fitting.

Using a double-blind procedure, an external member of the research team randomly assigned the new HAU to one of two groups: new HAUs-NRA ON or new HAUs-NRA OFF. Specifically, neither the participants nor the experimenter who administered the experimental test protocol knew which type of HA adjustments were used by the participants. For the new HAUs-NRA ON, all automatic features (NRA and DM) were activated as the recommended default settings in the Genie 2 software (Oticon 2019). For the new HAUs-NRA OFF in the Opensound Navigator section of the Genie 2 software, the directionality settings were set to pinna omni and the noise reduction was deactivated. In the Automatics section, the binaural coordination was deactivated. All new HAUs were fitted using the National Acoustics Laboratories Nonlinear 2 prescription target based on hearing thresholds (NAL-NL2: Keidser et al. 2011). Experienced HAUs completed the experimental protocol with their own personal HAs. To minimize any consequence on the acclimatization effect, no adjustments were made to the HAs during the course of the study. However, if during the initial meeting, the measured gain differed from NAL-NL2 prescription, fine modifications were made to improve speech intelligibility. The HAs of all the experienced HAUs were equipped with nonlinear circuits.

Using an Affinity 2.0 (Interacoustics 2017), real-ear insertion gain (REIG) was measured for all participants during the initial session (new and experienced HAUs). This procedure was applied to ensure that the information concerning the participant’s ear canal characteristics were obtained and accounted for in the fitting (Interacoustics 2015).

The new HAUs were informed that, if they successfully completed all the requirements of the study, they could keep the HAs assigned to them at no cost. Similarly, the experienced HAUs were informed that, upon completing all of the requirements of the experiment, they would receive a pair of Oticon OPN1 HAs, at no cost to them, at the end of the last testing session. All audiological services, including the tonal and speech audiometry, the REIG measurements and the pre-and post-orientation counseling on the use of HAs were provided by a trained audiologist at no cost to the participant.

Experimental procedure

During the pre-experimental session (S0), the experimenter (a trained audiologist) conducted a complete audiometric assessment including, otoscopy, immitancemetry, puretone air and bone conduction audiometry and speech audiometry using insert earphones with an Otometrics Madsen Astera audiometer (Otometrics 2009). The audiological tests were conducted in a sound-treated booth. If a person's hearing detection thresholds met the inclusion criteria for the study, the MoCA (Nasreddine et al., 2005) was administered. In addition, the following tests were administered to all the participants who took part in the study: Digit Symbol Substitution Test (DSST) (Weschler, 1939) and the Reading Span Test (RST) (Daneman & Carpenter, 1980). To investigate the effect of self-reported hearing disability on the acclimatization effect, new HAUs filled out a French version of the HHIE (HHIE-F: Adapted from the validated English version, Ventry & Weinstein, 1982). All the previously mentioned assessments were administered during S0. Then, a testing schedule was set for each participant. All participants were tested on the day of fitting (S1) and during 7 additional experimental test sessions that were held 2, 4, 6, 8, 14, 22 and 38 weeks post fitting (**Table 5.2)**.

Table 5.2. Schedule for testing sessions.

Experimental sessions	Pre-session (S0)	S1	S2	S3	S4	S5	S6	S7	S8
Week post-fitting	-	0	2	4	6	8	14	22	38

During the first experimental test session (S1), almost the same protocol was administered to all the participants of both experimental groups, namely: fitting of bilateral Oticon OPN 1 HAs (only for new HAUs), REIG measures, and the HINT under a single and a dual-task test condition. The secondary task consisted of a 3-stimuli TPRT (described in the following section). Before the dual-task condition was administered, a training block of TPRT trials was administered. All participants had to achieve a performance level of ≥80% correct responses during the training condition before performing the dual-task condition. During S1 to S8, the TPRT and the HINT were administered under both a single and dual-task condition. The testing order was the same for all experimental test sessions. The lists of HINT sentences used for the single and dual-task were counterbalanced. The full protocol is illustrated in **Figure 5.2**.

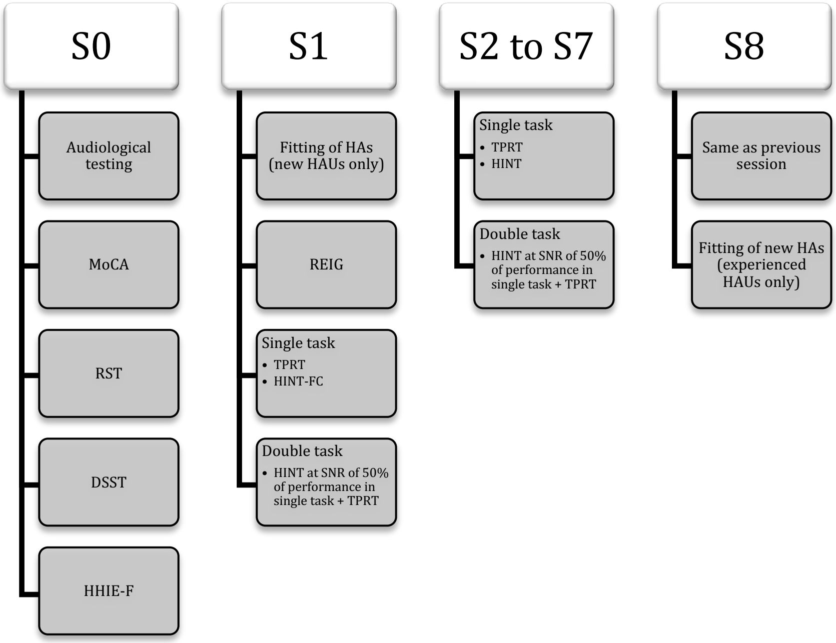

Figure 0.2. Test protocol for new and experienced HA users.

Dual-task paradigm

A dual-task paradigm was used to measure the listening effort expended to understand speech in noise.

The primary task consisted of a speech recognition test using the sentences from the French-Canadian version of the HINT (HINT$_{FC}$). The sentence lists were adapted and validated in Canadian-French (Vaillancourt et al. 2008; Vaillancourt et al. 2005). The speech material is comprised of 12 lists of 20 sentences. Also, there are 2 practice lists of 20 sentences. Each sentence is between 5 and 7 syllables in length.

The HINT$_{FC}$ consists of simple, high-context sentences. In this study the sentences were presented via a loudspeaker positioned at 0^O azimuth on the horizontal plane at a distance of one meter from the center of the participant's head. The speech material was heard in a background of speech spectrum noise provided by a loudspeaker positioned at 180^{O} azimuth on the horizontal plane at a distance of one meter from the center of the participant's head. The level of the speech spectrum noise, produced by the GSI audiometer (Grason-Stadler 2011), was fixed at 65 dB A and consisted of a white noise filtered to a low and middle frequency band. It is calibrated for equal energy per frequency from 250 to 1000 Hz with a 12 dB/ octave roll-off from 1000 to 6000 Hz.

Participants were requested to repeat the whole sentence out loud as best as they could. To be scored as correct, all the key words in a given sentence had to be repeated correctly. The $\mathrm{HINT}_{\mathrm{FC}}$ threshold is determined as the SNR (dB) at which the participant correctly repeats 50% of the sentences within a block of trials. The protocol used for the speech perception test in this study was adapted from the original HINT protocol (Nilsson et al. 1994).

During S1, the first sentence list used was presented at a fixed SNR of +2 dB. The SNR of the next sentence list was modified depending on the performance of the participant. If the participant obtained a score between 0% and 24%, the SNR was increased by 2 dB. If the percent correct score was between 25% and 44%, the SNR was increased of 1 dB. If the score was between 45% and 55%, the same SNR was used. If the score was between 56% and 75%, the SNR was reduced by 1 dB. Finally, if the score was between 76% and 100%, the SNR was reduced by 2 dB.

In order to target the SNR that yielded a performance level of 50% correct responses ±10%), the procedure described above was used during all the testing sessions. One modification was applied during S2–S8. Specifically, the initial practice list was set at the SNR that had yielded a score of approximately 50% correct during the previous test session. Under the dual-task condition, the SNR was fixed at the same level as the one that resulted in a performance score of 50% correct responses under the single-task condition administered during the same session.

The secondary task consisted of a TPRT for which participants had to identify the elements of a sequence of three consecutive stimuli that varied in duration (e.g. short-short-long, short-long-long, etc.). This task was modelled after a two-stimuli TPRT that had been used successfully to measure listening effort in older adults (Anderson Gosselin & Gagné 2011). The duration of the short pulse was 250 ms. The duration of the long stimulus was 500 ms. The inter-stimulus interval was 100 ms. The stimuli were played through a small oscillator (Radioear B-71) typically used for bone-conduction audiometry. When the task was administered under the dual-task condition, the vibrations started 100 ms after the onset of the auditory stimuli. The bone-vibrator was always placed in the participant's dominant hand. Specifically, the participant held the bone-vibrator in the palm of their hand and placed their hand in a cardboard box containing sound attenuating foam. The scores were computed for each vibration and was identified as correct when the participants accurately identified the duration of each stimulus. Hence, each sequence of three consecutive stimuli yielded three data points.

For each trial of the dual-task experimental condition, the participant was requested to first repeat the sentence they heard. Then, they were to identify the elements of the tactile pattern that had been presented by touching in the appropriate order with their free hand the iconic symbols of the tactile pattern they perceived. Two response alternatives were shown for each of the three elements that constituted a trial. For each element, the participants had to identify whether the vibration was short or long. Participants received feedback on their performance only when the TPRT was administered in the single-task condition. Participants were informed on whether they performed lower or higher than 80%. The tailor-made software developed for the experiment was used to record whether the response provided was correct as well as the RT of each answer.

Cognitive Assessment

The MoCA (Nasreddine et al. 2005) was administered to each participant. This test is administered using live voice. A personal amplification system (a pocket talker) was used when necessary. This brief cognitive screening instrument has been previously validated (Freitas et al. 2015; Gauthier et al. 2011) to measure global cognitive function. The MoCA is a one-page 30-points test administered in 10 minutes. The participant had to obtain a minimum score of 26 out of a maximum of 30 in order to be included in the study.

The French version of the RST was used in this study to measure working memory (Desmettes et al. 1985). This test is composed of 5 lists of 5 blocks of sentences. Participants are presented increasingly longer blocks of sentences on a computer screen (from 2 to 6 sentences per block). They are asked to read them out loud at their own pace without interruption while trying to remember the last word of each sentence. The participant reads one sentence and touches the screen monitor so that the next sentence is projected on the computer monitor. This procedure is followed until no more sentences are presented. Participants are then asked to repeat the last word of each sentence. The total score is then transformed as a percentage of the correctly remembered words.

The DSST was used to measure the speed of processing. The DSST is taken from the Wechsler Adult Intelligent Scale (Weschler 1939). It consists of numbers that are symbol-coded. This test is correlated with perceptual speed processing and executive functions (Baudouin et al. 2009; Salthouse 2000). The participant is asked to use the code table to associate each number to the corresponding symbol using a pen and the sheet of paper displaying the code table and symbol legend. On the same piece of paper, a row of double-boxes is presented with numbers in the top boxes and empty boxes underneath the numbers. The participant is asked to write the symbol (in the empty boxes) associated with a number. The score is calculated based on the number of correctly associated test items completed in 90 seconds.

Analysis

Three different dependent measures were used to investigate acclimatization to HAs. The first consisted of the performance level on the speech recognition task administered in noise. Specifically, the performance measure consisted of the change in SNR on the speech recognition test under the single task condition (where a more negative SNR represents a better performance). The second consisted of the proportional dual-task cost (pDTC) of the performance level obtained on the TPRT, the secondary task incorporated into the dual-task paradigm. To control for differences in baseline performance on the TPRT, the pDTC is computed using a proportional difference score (pDTC= [Secondary-task$_{\text{single task}}$ – Secondary task$_{\text{dual-task}}$] / [Secondary-task$_{\text{single task}}$ X 100]) (Fraser et al. 2010; Gagné et al. 2017). The third dependent measure was based on RT obtained on the TPRT when performed under the dual-task condition. Participants were asked to respond to the speech recognition task first and then perform the TPRT task. The data recorded by the software consisted of the total RT for both the primary and the secondary tasks. In order to obtain RT for the secondary task alone, the RT for the primary task was subtracted from the total RT registered by the software. Only RT for correct items on the primary task were considered for the analysis. The results obtained for each of the three dependent measures are presented in the results section. For each of the dependent variables, a two-way mixed design (between-within subjects) ANOVA was conducted to examine the effect of group and test session on acclimatization. Subsequently, if a significant interaction was present, post-hoc tests such as Bonferroni adjustments were performed to investigate the nature of the interaction. Pearson's r correlations were performed to investigate the relationship between independent variables (age, sex, perceived hearing handicap, severity of HL, working memory and speed of processing) and the acclimatization effect.

Results

Acclimatization effect

Performance on the speech recognition task administered in noise

The mean performance on the speech recognition task administered in noise obtained for each group of participants, at each test session, are displayed in **Figure 5.3**. A two-way mixed design ANOVA (between-within subjects) revealed a significant effect of Test Session ($F[7, 38] = 9.610$, $p < 0.001$, r=0.45), a significant Group effect ($F[2, 44] = 11.638$, $p < 0.001$, r=0.46) as well as a significant Group X Test Session interaction ($F[14, 76] = 3.14$,$p < 0.001$, r=0.2). First, post hoc tests were conducted to investigate the nature of the significant interaction. Pairwise comparisons using Bonferroni adjustments revealed that the experienced HAUs differed significantly from the new HAUs-NRA ON ($p < 0.001$) and from the new HAUs-NRA OFF ($p < 0.001$). The two new HAU groups did not differ from each other ($p = 0.935$).

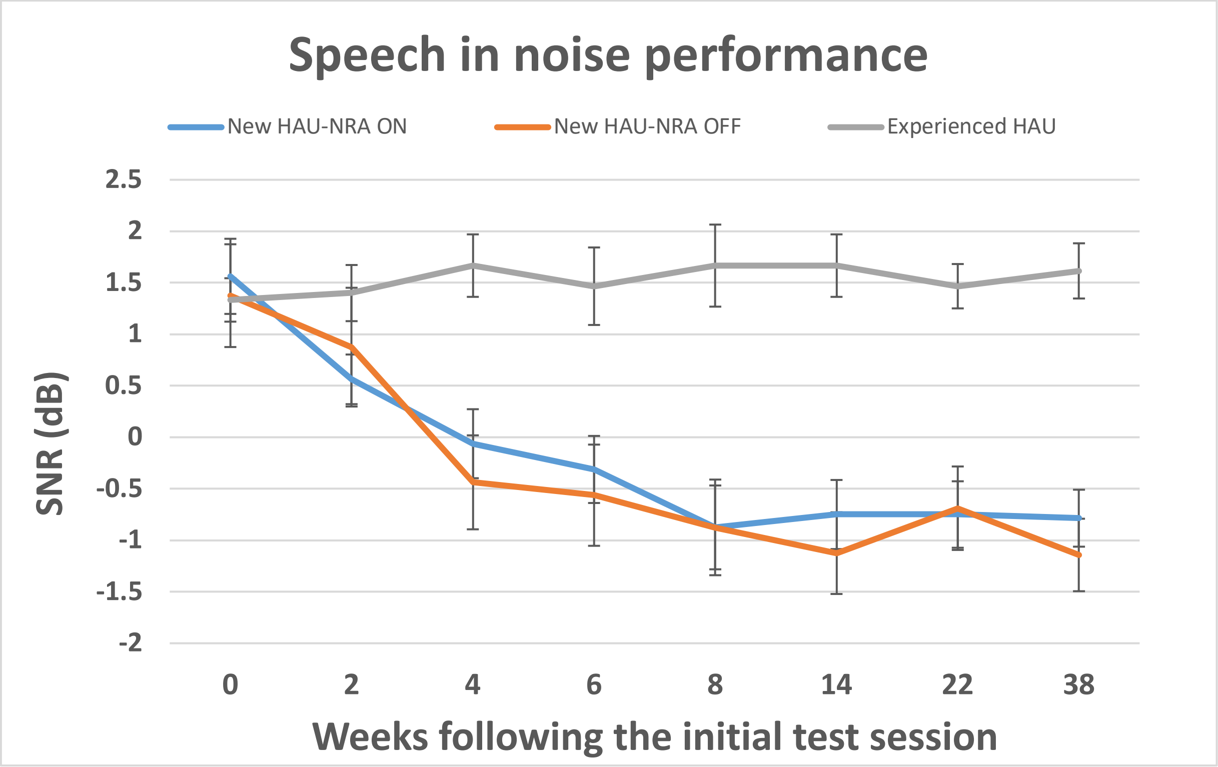

Figure 0.3. Acclimatization as measured by the performance on the speech in noise test as a function of NRA and DM activation. Error bars show ±1 standard error of the mean (SEM).

Separate 1-way ANOVAs (repeated measures), one for each group, were conducted to investigate differences in performance across the 8 test sessions. For the experienced HAUs, the results revealed no significant effect of Test Sessions ($F[7, 98] = 0.397$, $p = 0.902$, r=0.06). For both groups of new HAUs, the results revealed a significant effect of Test Session; for the new HAUs-NRA OFF group ($F[7, 105] = 14.310$,$p < 0.001$, r=0.35) and the new HAUs-NRA ON group ($F[7, 105] = 12.422$, $p < 0.001$, r=0.33). Paired samples test for each test sessions are presented in **Table 5.3** for new HAUs-NRA OFF and in **Table 5.4** for new HAUs-NRA ON.

Table 5.3. Paired samples test for new HAU-NRA OFF.

Weeks	**0**	**2**	**4**	**6**	**8**	**14**	**22**	**38**
0	-	0.006	***0.000****	***0.001****	***0.000****	***0.000****	***0.000****	***0.000****
2		-	0.003	***0.001****	***0.000****	***0.000****	***0.001****	***0.000****
4			-	0.333	0.007	0.044	0.102	0.014
6				-	0.188	0.13	0.069	0.029
8					-	0.743	0.806	0.796
14						-	1.00	0.870
22							-	0.859
38								-

* Two-tailed significant at the 0.002 probability level (with Bonferonni correction)

Table 5.4. Paired samples test for new HAU-NRA ON

Weeks	**0**	**2**	**4**	**6**	**8**	**14**	**22**	**38**
0	-	0.178	***0.000****	***0.000****	***0.000****	***0.000****	***0.001****	***0.000****
2		-	0.031	0.012	***0.001****	***0.000****	0.003	***0.000****
4			-	0.633	0.186	0.077	0.570	0.040
6				-	0.173	0.236	0.733	0.116
8					-	0.468	0.512	0.369
14						-	0.250	0.942
22							-	0.057
38								-

* Two-tailed significant at the 0.002 probability level (with Bonferonni correction)

Listening effort using the pDTC based on performance on the TPRT task

The pDTC performance on the secondary task (TPRT) of the dual-task paradigm obtained for each group, and at each test session, are displayed in **Figure 5.4**. A 2-way mixed design ANOVA (between-within subjects) failed to reveal a significant effect of Test Session (*F*[7, 37] = 1.881, *p* = 0.101, *r*=0.22) and of Group (*F*[2, 43] = 2.256, *p* = 0.117, *r*=0.22). Also, the Group X Test Session interaction was not significant (*F*[14, 76] = 0.537, *p* = 0.905, *r*=0.08).

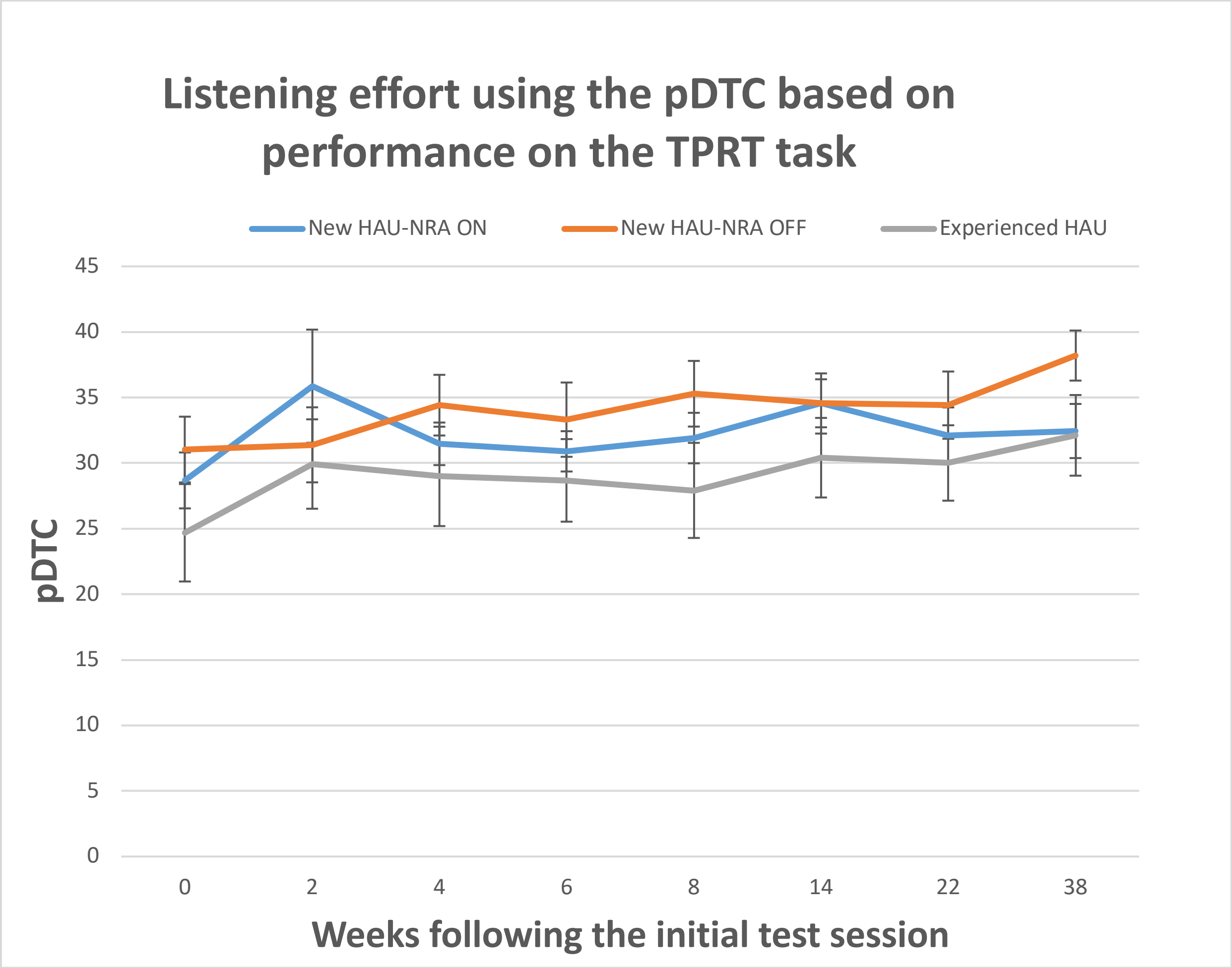

Figure 0.4. Acclimatization as measured by the pDTC based on the TPRT task for three groups of participants (new HAUS-NRA ON, new HAUs-NRA OFF and Experiences HAUs) as a function of test session. Error bars show ±1 standard error of the mean (SEM).

The RT on the secondary task (dual task condition) obtained for each group and at each test session are displayed in **Figure 5.5**. A 2-way mixed design ANOVA (between-within subjects) revealed no significant effect of Group (*F*[2, 44] = 1.389, *p* = 0.260, *r*=0.17), no significant effect of Test Session (*F*[7, 38] = 1.176, *p* = 0.339, *r*=0.17) and no significant Group X Test Session interaction (*F*[14, 78] = 1.561, *p* = 0.110, *r*=0.14).

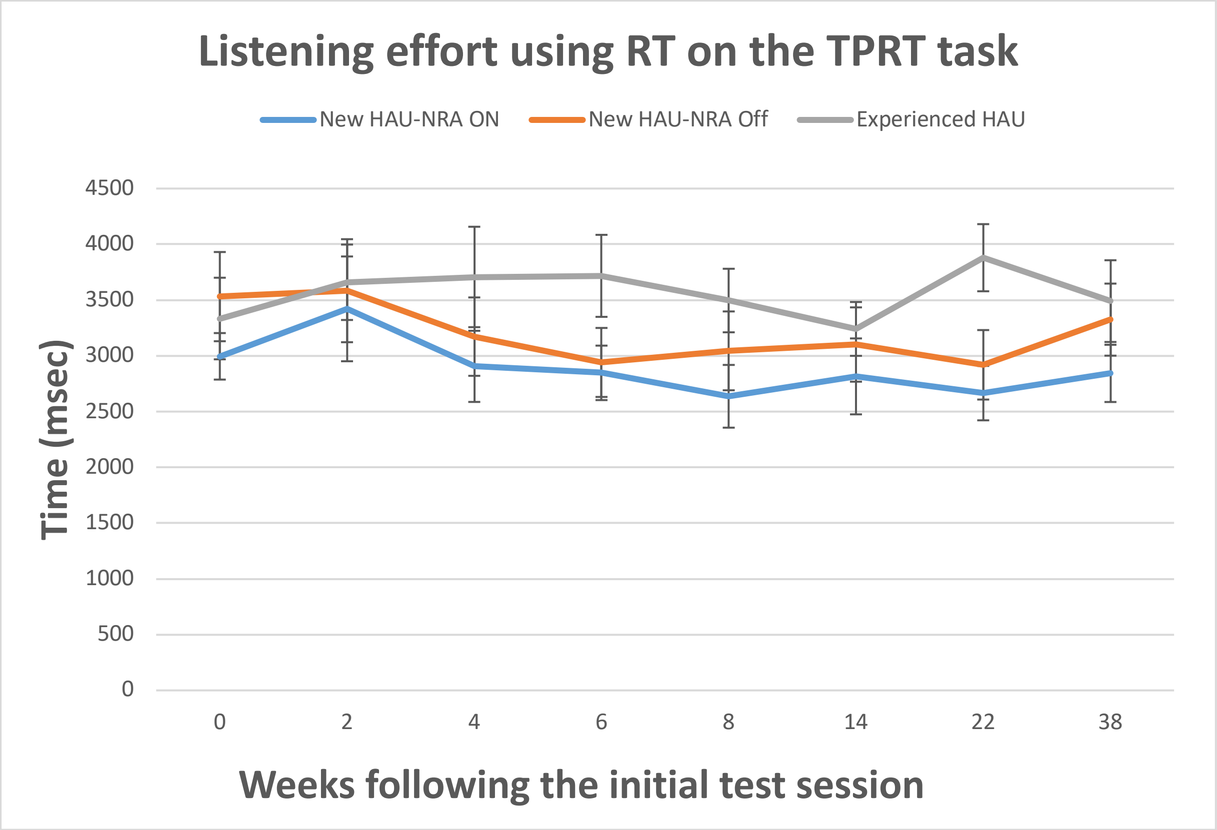

Figure 0.5. Acclimatization as measured by the RT on the TPRT task as a function of NRA and DM activation. Error bars show ±1 standard error of the mean (SEM).

Characteristics of the acclimatization effect

Time course of acclimatization

The starting point of the acclimatization effect was operationally defined as the test session at which the SNR obtained on the speech in noise test differed significantly from the SNR obtained during the S1 (i.e. the day that the participants of both experimental groups were fitted with new HAs). The acclimatization effect was deemed to be completed at the earliest test session at which the SNR obtained failed to differ significantly from the SNR obtained during the last session (S8). For the new HAUs-NRA OFF and the new HAUs-NRA ON, the acclimatization effect begins and reaches a plateau at week 4 (see Table 3 and 4, respectively).

Amplitude of the acclimatization effect

The amplitude of the acclimatization effect was defined as the change in SNR on the speech recognition task in noise between week 0 (S1) and week 22 (S7). The final performance at week 22 was chosen for two reasons: (1) there are no significant differences in SNR between the results obtained at week 22 and those obtained at week 38 (*p* = 0.345); and, (2) week 22 was the last test session attended for five participants. For new HAUs-NRA OFF, changes in SNR ranged from 0 to -5 dB, with an average change on the speech recognition task of -2.2 dB SNR. For the new HAUs-NRA ON, changes in SNR ranged from 0 to -6 dB SNR, with an average change on the speech recognition task of -2.1 dB SNR. A paired t-test revealed that the amplitude of the acclimatization did not differ significantly between both groups of new HAUs (p=0.836).

Predicting factors of the acclimatization effect

In order to identify which factors might explain the variance in the acclimatization effect among the new HAUs, bivariate correlations were computed for each independent variable and the amplitude of the acclimatization (in SNR) between week 0 and week 22. Both new HAUs groups were pooled together for greater statistical power (see **Table 5.5**).

The independent variables analyzed included: daily use of HAs, severity of HL, age, sex, perceived hearing handicap, working memory capacity (measured with RST) and speed of processing (measured with DSST).

First, HA use was characterized by extracting datalogging of HAs at each testing session to determine the average hours per day of HA use. Across the 32 new HAUs, the mean datalogging at the end of the study ranged from 9.2 to 14.6 hours per day (M=11.97, SD=1.64). Second, the average of hearing thresholds at 500, 1000 and 2000 Hz of both ears measured at S0 were used to determine the severity of HL. Those frequencies were chosen because the French-Canadian version of the HINT sentences has a specific sensitivity to frequencies below

2 kHz (Giguère, C., Reference Note 1). The severity of HL ranged from 4.7 to 38.3 dB HL (M=27.6, SD=8.8). Third, at the beginning of the study, the age of the new HAUs ranged from 63 to 75 years (M=70.2, SD=3). Fourth, working memory capacity was characterized by the score on the RST measured at S0 and ranged from 5 to 51.7% (M=28.1, SD=10.7). Fifth, speed of processing consisted of the score on the DSST measured at S0 and ranged from 19 to 48 (M=31.4, SD=6.8). Lastly, the perceived hearing handicap was measured during the initial test sessions (S0) with the HHIE-F. The results, representing the overall score on the HHIE-F questionnaire, ranged from 2 to 82 (M=29.1, SD=17.2).

Table 5.5. Bivariate correlations between independent variables and amplitude of acclimatization (week 0 to week 22).

Independent variables	*Pearson r (sig. 2-tailed)*
Dans Daily HA use	-0.02 (*p* =0.915)
Severity of hearing loss	0.354 (*p* =0.047*)
Age	-0.031 (*p* =0.866)
Sex	-0.231 (*p* =0.203)
Perceived hearing handicap	0.287 (*p* =0.138)
Working memory	0.197 (*p* =0.280)
Speed of processing	0.208 (*p* =0.253)

*Two-tailed significant at the 0.05 probability level

There is a moderate positive relationship between the severity of HL and the amplitude of the acclimatization effect (r=0.354, *p* =0.047). The greater the HL, the more pronounced the amplitude of the acclimatization effect. When baseline performance is controlled for, the relationship between the severity of HL and the amplitude of the acclimatization effect becomes weak and non-significant (r=0168, p=0.366).

Cognitive abilities

In the current study, working memory and speed of processing were selected to investigate the effects of cognitive abilities on acclimatization to HAs. As shown in Table 5, neither working memory nor speed of processing was significantly correlated to amplitude of acclimatization.

Discussion

The objectives of this study were (1) to determine whether listening effort, as measured with a dual-task experiment paradigm, can be used to investigate acclimatization to HAs by older adults with HL, (2) to investigate the effect of NRA and DM on HA acclimatization, (3) to characterize the time course of HA acclimatization and (4) to measure the correlation between working memory, speed of processing and reported hearing disability and the acclimatization period.

The main strengths of the present investigation are: (1) Results were obtained from a group of experienced HAUs in order to control for improvement in performance on the dependent measures due to practice effects; and, (2) Datalogging measures were used to obtain an objective measure of each participant’s HA use.

Presence of hearing aid acclimatization

Performance on the speech recognition task administered in noise

Using a speech recognition test administered in noise, a significant acclimatization effect was observed only for both groups of new HAUs. For these two groups the SNR at which they obtained the criterion performance level on the speech in noise task changed as a function of time and reached a plateau before the end of the test sessions. No improvement on the speech recognition task was observed for the experienced HAUs. A limitation in previous studies on acclimatization was the absence of control groups which can lead to a carry-over effect (Gatehouse 1992; Pinheiro et al. 2012; Yund et al. 2006). These results indicate the existence of an acclimatization effect and are consistent with the results reported by previous investigators (Cox et al. 1996; Gatehouse 1992; Reber & Kompis 2005).

One could have expected the initial performance from the experienced HAUs to be better than the initial performance from the new HAUs. However, as shown in Figure 3, the initial performance of the new HAUs and the experienced HAUs were similar. One possible explanation for this result is that the experienced HAUs had poorer hearing than the new HAUs.

Several methodological issues addressed in the experimental paradigm may have made it possible to observe a significant acclimatization effect. First, only individuals who used their HAs a minimum of 6 hours/day were retained as participants. All new HAUs wore their HAs for at least 9 hrs/day with an average of 12 hrs/day. Investigators who did not incorporate this criterion in their experimental design did not observe an acclimatization effect (Petry et al. 2010; Saunders & Cienkowski 1997). It is reasonable to expect that adaptation to the perception of new acoustic cues may be limited for new HAUs who do not use their HAs or use them only on a part-time basis. Second, all the participants had a HL in both ears and they were fitted bilaterally with HAs. Some studies that did not measure an acclimatization effect included participants with unilateral HA fittings (Dawes et al., 2014; Taylor, 1993). Because the acclimatization effect, when observed, is small, a possible explanation for studies that did not observe acclimatization is that it may take longer to optimize the benefits provided by a HA if the non-aided ear is not experiencing the same acoustical stimulation. This is especially true if the outcome measure is a speech recognition task in free-field stimulation. Acclimatization to a HA may be smaller when the HA is worn only in one ear which can hide a small acclimatization effect in the fitted ear (Bentler et al. 1993; Song et al. 2011).

Listening effort

The results obtained with the two dependent variables assessing listening effort (pDTC and RT) failed to reveal a significant acclimatization effect in any of the three groups of participants. Several reasons may account for this finding. First it is possible that listening effort does not change after the initial fitting of a HA. However, the results may also be due to the experimental paradigm used and specifically to the primary and the secondary tasks employed. Gagné et al., (2017) stated that when a dual-task paradigm is used to measure listening effort the results obtained will be influenced by the type of tasks used and especially the relative level of difficulty of those tasks.

The primary task used in the present study had a relatively high level of difficulty (i.e., the SNR at which a participant obtained a sentence recognition score of 50% correct responses). Other investigators report a listening effort effect when they used an easier performance criterion for their primary task. For example, Desjardins and Doherty (2013) fixed the primary task performance at 76% and found a significant effect of type of masker on speech recognition in noise performance using a dual-task paradigm. Similarly, Anderson Gosselin and Gagné (2011) used 80% performance level for the primary task and the TPRT with a 2-stimuli sequence as the secondary task to successfully observe that older adults expend significantly more effort than young adults to recognize speech in noise. While most studies used a fixed performance level for the primary tasks of 75% or more, some investigators reported a significant effect of listening effort when the performance criterion on the primary task is set at a lower level. Picou et al. (2013) used individual performances of 60% on a monosyllable word recognition task. The secondary task was a visual reaction time task. The results revealed that HAs can significantly reduce listening effort.

An additional limitation relative to the primary task is that the French-Canadian version of the HINT sentences is intensity specific to frequencies below 2 kHz. As shown in Figure 1, participants in this study had high-frequency HL starting at 2 kHz. Hence, the speech material used in this study may not have measured the acclimatization effect that occurred at audiometric frequencies above 2 kHz (Saunders & Cienkowski, 1997). Individuals with age-related HL tend to have the greatest amount of HL above 2 kHz (Huang & Tang 2010). For individuals with high-frequency hearing thresholds of less than 55-60 dB HL, making high-frequencies available improves speech intelligibility (Hogan & Turner,1998; Turner & Cummings, 1999). Using an experimental group similar to the one in the current study, new HAUs with high frequency hearing thresholds below 60 dB HL and target amplification reached in high frequencies, it would be important to measure acclimatization with test material that is characterized by having a considerable amount of spectral energy at frequencies above 2 KHz.

Similarly, relative to the primary task, the level of difficulty of the secondary task will influence whether listening effort can be measured. All previous studies using the TPRT as the secondary task used a 2-stimuli sequence of tones instead of a 3-stimuli sequence as was used in the present study. For example, Fraser et al. (2010) used a speech recognition task in audiovisual and audio-only modalities at an 80% performance level as the primary task and the TPRT as a secondary task with two elements. The authors concluded that when the same performance level was used for the audio-only and the audiovisual speech recognition task, more listening effort was expended when performing the later task. In the present study, the mean performance level on the TPRT under the single task condition was of 86% correct (SD=5%). However, the performance level observed on the secondary task under the dual-task condition yielded results that were near chance performance (the mean performance was 56.8% correct [SD=5.7] and chance performance would yield a 50% score). These results indicate that TPRT data in dual-task condition is near the floor effect limit. As explained by the FUEL model, when the level of performance is less than the acceptable performance level, a listener is unlikely to sustain attention and might give up listening (Pichora-Fuller et al. 2016). In the present study, the combination of the primary task and the secondary task may have been too difficult for the listeners to sustain listening effort in order to obtain a higher level of performance on the secondary task. It is possible that a less difficult secondary task may have made it possible for the participants in the experimental groups to improve their performance on the TPRT task as a function of test session.

Using RT as a dependent variable for the secondary task failed to reveal differences in performance across the three groups of participants. This finding is surprising because other investigators have shown RT to be a sensitive measure to listening effort. For example, Neher et al. (2014) used a sentence recognition in noise test as a primary task and a visual response time measure as the dependent variable for the secondary task. Results revealed shorter RTs on the secondary task when the sentences used for the primary task were presented at a more favorable SNR. Wu et al. (2016) measured listening effort with a dual-task paradigm using the HINT as the primary task and two secondary tasks, a visual RT task and the incongruent Stroop test. The RT on both secondary tasks were used as the dependent variables. The results revealed longer RTs (more listening effort expended) when the SNR was set to yield performance levels ranging from 30% to 50% correct scores (Wu et al. 2016). According to the investigators, the shorter RTs obtained when unfavorable SNRs are used (yielding performance levels below 30% correct) suggest that when the task is too taxing, participants experience cognitive overload and tend to give up (Petersen et al. 2015; Wu et al. 2016). In the present experience, although the HINT was performed at fixed SNRs of 50%, under the dual-task condition the difficulty of the secondary task may have been too taxing to accurately measure listening effort.

In the future, in order to determine whether listening effort decreases as a function of HA use among first-time users (i.e., an acclimatization effect based on listening effort rather than performance on a speech recognition task) it will be critical to choose pairs of primary and secondary tasks that have been shown to produce a change in listening effect under different experimental conditions (e.g., with vs. without HAs) and for participants with similar personal characteristics (e.g., older adults with mild-moderate HL).

Effect of noise reduction algorithms and directional microphones on acclimatization

Because results showed an acclimatization effect for both groups of new HAUs, it may be concluded that an acclimatization effect occurs regardless of whether the HAs fitted have NRA or DM. No significant difference in magnitude and in time-course of acclimatization was observed.

To our knowledge, no previous studies have investigated the effect of NRA and DM on HA acclimatization. In the future, it may be of interest to investigate the effects of each of the two noise reduction methods (DM or NRA) separately in order to ascertain how each of them contribute to the magnitude and time course of the acclimatization effect reported in the present investigation. Moreover, it would be interesting to investigate whether the activation of NRA and DM in daily-life influences the acclimatization effect. In the present study, the Oticon software did not retrieve this information.

Characteristics of hearing aid acclimatization

The magnitude and the time course of the acclimatization effect observed in this study is similar to the results reported by Dawes and Munro (2016). In that study, participants with an average puretone HL greater than 40 dB HL and who used their HAs more than 6 hrs per day displayed a significant acclimatization effect after 30 days of HA use. The similarity with the present experiment is that both studies used nonlinear amplification, bilateral HA fittings and HA use was accounted for using datalogging.

Magnitude and time course of acclimatization

On average the new HAUs improved their performance by approximately 2 dB over a period of 4 weeks. Taylor and Mueller (2016) state that for individuals with HL, each dB improvement in SNR (at a performance level of 50% correct on the psychometric function) yields an improvement score of approximately 10% on a speech recognition in noise task. Although 2 dB SNR may be considered a small improvement, these results suggest that over the 4 weeks acclimatizing period participants may improve their ability to recognize speech in noise by as much as 20%.

The time course of the acclimatization found in this study is shorter than the time-frame proposed by Gatehouse (1993) who suggested that the acclimatization starts at around 6-8 weeks post HA fitting and reaches a plateau at about 16 weeks post fitting. A possible explanation for this discrepancy is that Gatehouse (1993) used unilateral HA fittings. It may take longer to optimize the benefits provided by a HA if the non-aided ear is not experiencing the same acoustical stimulation. In addition, Gatehouse (1993) used HAs with linear technology. Digital WDRC HAs were used in the current study. The compression and other non-linear acoustic manipulations implemented in most contemporary HAs can provide better speech intelligibility (Kam & Wong 1999; Rhebergen et al. 2017). It may be easier to adapt to these types of aids.

Predicting factors of acclimatization

Bivariate correlation analyses were conducted for the acclimatization measure using the performance on the HINT_{FC} (change in SNR to reach a performance of 50% correct). Dawes and Munro (2016), reported an acclimatization effect only for a subgroup of participants who used HAs at least 6 hours per day. In the present study amount of HA use did not influence the acclimatization period. The absence of correlation between HA use and acclimatization in this study may be attributable to the fact that all participants wore their HAs for at least 9 hours per day (M=11.97, SD=1.64). Perhaps, once a certain use-threshold is reached (e.g., 6 hours/day) HA use is not correlated with acclimatization to HAs.

The only significant factor correlated with acclimatization effect was the severity of HL. The more severe the HL, the greater the performance on the speech perception in noise task improved. This is consistent with Dawes and Munro (2016) who found a significant correlation between improvement on the speech recognition in noise performance and severity of HL. However, it should be noted that once the baseline performance is controlled for, there is no significant correlation between degree of HL and the magnitude of the acclimatization effect. It is possible that the significant correlation is due to the fact that individuals with poorer hearing thresholds may have more room for improvement.

Relationship between cognitive abilities and hearing aid acclimatization

Cognitive abilities are associated to speech recognition in noise and have been associated with HA success, post-fitting (Lunner et al. 2009; Nuesse et al. 2018; Pichora-Fuller & Singh 2006; Stenfelt & Ronnberg 2009). In the present study, no correlations were found between acclimatization and two cognitive abilities, namely speed of processing and working memory. Acclimatization to HAs may not be influenced by these two cognitive abilities. Alternatively, the tests used to measure speed of processing and working memory may not have been sufficiently sensitive to observe differences. For example, Daneman and Carpenter (1980) suggested that individual differences in ease of reading comprehension may affect the specificity of the test as the higher scores for good readers are interpreted as better working memory. Additionally, while the DSST is a sensitive measure of the presence of cognitive dysfunction, it is not a specific measure of the speed of processing (Jaeger 2018). More research is needed to examine whether there exists a relationship between cognitive function and acclimatization to HAs.

Clinical implications

Results support offering new HAUs a trial period so that they can better appreciate the improvement provided by the amplification, especially related to speech understanding under noisy listening conditions. Furthermore, the results suggest that regardless of the HA technology implemented in the HAs, the acclimatization effect should be completed within a period of two months. Based on these results it would be advisable for dispensing audiologists to consider extending the HA trial period up to 2-months given that some new HA users may need that amount of time to optimize the benefits provided by amplified speech. Moreover, it would be of importance for the audiologist to consider and discuss with the new HAUs of the possible effect of HL on the acclimatization to HAs.

Conclusion

Improvement over time in aided speech recognition in noise as measured by performance on the HINT_{FC} was observed for new HAUs compared to a control group of experienced HAUs. The acclimatization effect was in the order of a 2 dB change in SNR over a period of 4weeks for a sentence recognition task administered in noise. Based on the present findings as well as results of a previous study (Dawes & Munro 2016) an average minimum HA use of 6 – 9 hours per day may be needed to exhibit an acclimatization effect. Also, the magnitude of the acclimatization effect is larger among participants who have a greater amount of HL as measured by the PTA (0.5, 1 and 2 kHz).

Using a dual-task paradigm (pDTC and RT from the secondary task) failed to reveal an acclimatization effect. The activation of NRA and DM did not influence the acclimatization effect observed. Cognitive functions, namely WMC and speed of processing, did not correlate with the magnitude of the acclimatization effect. This study supports the claim that sustained daily use of HAs leads to an auditory acclimatization effect.

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D.W. and J.P.G. designed and wrote the paper; DW performed experiments and analyzed data.

Both authors contributed equally to this work. The authors discussed the results and implications and commented on the manuscript at all stages.

References

Anderson Gosselin, P., & Gagné, J. P. (2011). Older adults expend more listening effort than young adults recognizing speech in noise. *Journal of Speech Language and Hearing Research, 54*(3), 944-958. doi:10.1044/1092-4388(2010/10-0069)

Arlinger, S., et al. (1996). Report of the Eriksholm Workshop on auditory deprivation and acclimatization. *Ear and Hearing, 17*(3 Suppl), 87S-98S.

Barker, F., et al. (2014). Interventions to improve hearing aid use in adult auditory rehabilitation. *Cochrane Database Systematic Reviews,* (7), CD010342. doi:10.1002/14651858.CD010342.pub2

Baudouin, A., et al. (2009). Executive functioning and processing speed in age-related differences in memory: contribution of a coding task. *Brain Cognition, 71*(3), 240-245. doi:10.1016/j.bandc.2009.08.007

Bentler, R. A., et al. (1993). Longitudinal study of hearing aid effectiveness. I: Objective measures. *Journal of Speech Hearing Research, 36*(4), 808-819.

Brons, I., et al. (2014). Effects of noise reduction on speech intelligibility, perceived listening effort, and personal preference in hearing-impaired listeners. *Trends in Hearing, 18*. doi:10.1177/2331216514553924

Cox, R. M., & Alexander, G. C. (1992). Maturation of hearing aid benefit: objective and subjective measurements. *Earand Hearing, 13*(3), 131-141.

Cox, R. M., et al. (1996). Benefit acclimatization in elderly hearing aid users. *Journal of the American Academy of Audiology, 7*(6), 428-441.

Daneman, M., & Carpenter, P. A. (1980). Individual differences in working memory and reading. *Journal of Verbal Learning and Verbal Behavior, 19*(4), 450-466. doi:https://doi.org/10.1016/S0022-5371(80)90312-6

Dawes, P., & Munro, K. J. (2016). Auditory distraction and acclimatization to hearing aids. *Ear and Hearing, 38*(2), 174-183.

Dawes, P., et al. (2014). Auditory acclimatization and hearing aids: late auditory evoked potentials and speech recognition following unilateral and bilateral amplification. *Journal of Acoustical Society of America, 135*(6), 3560-3569. doi:10.1121/1.4874629

Desjardins, J. L., & Doherty, K. A. (2013). Age-related changes in listening effort for various types of masker noises. *Ear and Hearing, 34*(3), 261-272. doi:10.1097/AUD.0b013e31826d0ba4

Desjardins, J. L., & Doherty, K. A. (2014). The effect of hearing aid noise reduction on listening effort in hearing-impaired adults. *Ear and Hearing, 35*(6), 600-610. doi:10.1097/AUD.0000000000000028

Desmettes, D., et al. (1985). Adaptation en langue française du “Reading Span Test” de Daneman et Carpenter (1980). *Annee psychology, 95*(3), 459-482.

Folstein, M. F., et al. (1975). "Mini-mental state". A practical method for grading the cognitive state of patients for the clinician. *Journal of Psychiatric Research, 12*(3), 189-198.

Foster, J. R., & Haggard, M. P. (1979). An effective analytical test of speech perception. *Proceedings of the Institute of Acoustics, 182*, 9-12.

Foster, J. R., & Haggard, M. P. (1987). The four alternative auditory feature test (FAAF)- linguistic and psychometric properties of the material with normative data in noise. *British Journal of Audiology, 21*, 165-174.

Fraser, S., et al. (2010). Evaluating the effort expended to understand speech in noise using a dual-task paradigm: the effects of providing visual speech cues. *Journal of Speech Language and Hearing Research, 53*(1), 18-33. doi:10.1044/1092-4388(2009/08-0140)

Freitas, S., et al. (2015). Scaling Cognitive Domains of the Montreal Cognitive Assessment: An Analysis Using the Partial Credit Model. *Archives of Clinical Neuropsychology*. doi:10.1093/arclin/acv027

Gagné, J. P., et al. (2017). Behavioral Assessment of Listening Effort Using a Dual-Task Paradigm. *Trends in Hearing, 21*, 2331216516687287. doi:10.1177/2331216516687287

Gatehouse, S. (1989). Apparent auditory deprivation effects of late onset: the role of presentation level. *Journal o the Acoustical Society of America, 86*(6), 2103-2106.

Gatehouse, S. (1992). The time course and magnitude of perceptual acclimatization to frequency responses: evidence from monaural fitting of hearing aids. *Journal of the Acoustical Society of America, 92*(3), 1258-1268.

Gatehouse, S. (1993). Role of perceptual acclimatization in the selection of frequency responses for hearing aids. *Journal of the American Academy of Audiology, 4*(5), 296-306.

Gauthier, S., et al. (2011). Commentary on "Recommendations from the National Institute on Aging-Alzheimer's Association workgroups on diagnostic guidelines for Alzheimer's disease." A Canadian perspective. *Alzheimers Dement, 7*(3), 330-332. doi:10.1016/j.jalz.2011.03.006

Gnewikow, D., & Moss, M. (2006). Hearing aid outcomes with open- and closed-canal fittings. *Hearing Journal, 59*(11), 68-70.

Grason-Stadler. (2011). GSI User Manual.

Hogan, C. A., & Turner, C. W. (1998). High-frequency audibility: benefits for hearing-impaired listeners. *Jounrla of the Acoustical Society of America, 104*(1), 432-441. doi:10.1121/1.423247

Huang, Q., & Tang, J. (2010). Age-related hearing loss or presbycusis. *European Archives of Otorhinolaryngology, 267*(8), 1179-1191. doi:10.1007/s00405-010-1270-7

Humes, L. E., et al. (2002). Changes in hearing-aid benefit following 1 or 2 years of hearing-aid use by older adults. *Journal of Speech Language and Hearing Research, 45*(4), 772-782.

Humes, L. E., et al. (2003). Examination of differences between successful and unsuccessful elderly hearing aid candidates matched for age, hearing loss and gender. *International Journal of Audiology, 42*(7), 432-441.

Interacoustics. (2015). Affinity 2.0. *A Complete Solution.* Retrieved from http://www.interacoustics.ca/affinity

Interacoustics. (2017). Affinity 2.0- Hearing Aid Analyzer. *Technical specifications.* Retrieved from https://www.interacoustics.com/support/affinity

Jaeger, J. (2018). Digit Symbol Substitution Test: The Case for Sensitivity Over Specificity in Neuropsychological Testing. *Journal of Clinical Psychopharmacology, 38*(5), 513-519. doi:10.1097/JCP.0000000000000941

Kam, A. C., & Wong, L. L. (1999). Comparison of performance with wide dynamic range compression and linear amplification. *Journal of the American Academy of Audiology, 10*(8), 445-457.

Keidser, G., et al. (2011). The NAL-NL2 Prescription Procedure. *Audiology Research, 1*(1), e24. doi:10.4081/audiores.2011.e24

Knudsen, L. V., et al. (2010). Factors influencing help seeking, hearing aid uptake, hearing aid use and satisfaction with hearing aids: a review of the literature. *Trends in Amplification, 14*(3), 127-154. doi:10.1177/1084713810385712

Lunner, T., et al. (2009). Cognition and hearing aids. *Scandinavian Journal of Psychology, 50*(5), 395-403. doi:10.1111/j.1467-9450.2009.00742.x

McCoy, S. L., et al. (2005). Hearing loss and perceptual effort: downstream effects on older adults' memory for speech. *Quarterly Journal of Experimental Psychology A, 58*(1), 22-33. doi:10.1080/02724980443000151

McGarrigle, R., et al. (2014). Listening effort and fatigue: what exactly are we measuring? A British Society of Audiology Cognition in Hearing Special Interest Group 'white paper'. *Internation Journal of Audiology, 53*(7), 433-440. doi:10.3109/14992027.2014.890296

Munro, K. J., & Lutman, M. E. (2003). The effect of speech presentation level on measurement of auditory acclimatization to amplified speech. *Journal of the Acoustical Society of America, 114*(1), 484-495.

Nasreddine, Z. S., et al. (2005). The Montreal Cognitive Assessment, MoCA: a brief screening tool for mild cognitive impairment. *Journal of the American Geriatrics Society, 53*(4), 695-699. doi:10.1111/j.1532-5415.2005.53221.x

Neher, T., et al. (2014). Do hearing loss and cognitive function modulate benefit from different binaural noise-reduction settings? *Ear and Hearing, 35*(3), e52-62. doi:10.1097/AUD.0000000000000003

Nilsson, M., et al. (1994). Development of the Hearing in Noise Test for the measurement of speech reception thresholds in quiet and in noise. *Journal of the Acoustical Society of America, 95*(2), 1085-1099. doi:10.1121/1.408469

Nuesse, T., et al. (2018). Exploring the Link Between Cognitive Abilities and Speech Recognition in the Elderly Under Different Listening Conditions. *Frontiers in Psychology, 9*, 678. doi:10.3389/fpsyg.2018.00678

Ohlenforst, B., et al. (2017). Effects of Hearing Impairment and Hearing Aid Amplification on Listening Effort: A Systematic Review. *Ear and Hearing, 38*(3), 267-281. doi:10.1097/AUD.0000000000000396

Oticon. (2019). Genie Key Features. Retrieved from https://www.oticon.com/professionals/tools-and-support/fitting/key-features

Otometrics. (2009). MADSEN Astera Brochure. Retrieved from https://pdf.medicalexpo.com/pdf/otometrics/madsen-astera-brochure/70796-75879.html

Palmer, C. V., et al. (1998). The functionally and physiologically plastic adult auditory system. *Journal of the Acoustical Society of America, 103*(4), 1705-1721.

Pals, C., et al. (2015). Validation of a simple response-time measure of listening effort. *Journal of the Acoustical Society of America, 138*(3), EL187-192. doi:10.1121/1.4929614

Petersen, E. B., et al. (2015). Hearing loss impacts neural alpha oscillations under adverse listening conditions. *Frontiers in Psychology, 6*, 177. doi:10.3389/fpsyg.2015.00177

Petry, T., et al. (2010). Speech recognition according to the length of hearing aid use. *Brazilian Journal of Otorhinolaryngology, 76*(4), 462-468.

Pichora-Fuller, M. K., et al. (2016). Hearing Impairment and Cognitive Energy: The Framework for Understanding Effortful Listening (FUEL). *Ear and Hearing, 37 Suppl 1*, 5S-27S. doi:10.1097/AUD.0000000000000312

Pichora-Fuller, M. K., & Singh, G. (2006). Effects of age on auditory and cognitive processing: implications for hearing aid fitting and audiologic rehabilitation. *Trends in Amplification, 10*(1), 29-59. doi:10.1177/108471380601000103

Picou, E. M., et al. (2013). How hearing aids, background noise, and visual cues influence objective listening effort. *Ear and Hearing, 34*(5), e52-64. doi:10.1097/AUD.0b013e31827f0431

Pinheiro, M. M., et al. (2012). The influence of cognitive aspects and auditory processes on the hearing aid acclimatization in the elderly. *Journal da Sociedade Brasileira de Fonoaudiologica, 24*(4), 309-315.

Rakerd, B., et al. (1996). Assessing the cognitive demands of speech listening for people with hearing losses. *Ear and Hearing, 17*(2), 97-106.

Reber, M. B., & Kompis, M. (2005). Acclimatization in first-time hearing aid users using three different fitting protocols. *Auris Nasus Larynx, 32*(4), 345-351. doi:10.1016/j.anl.2005.05.008

Rhebergen, K. S., et al. (2017). Characterizing Speech Intelligibility in Noise After Wide Dynamic Range Compression. *Ear and Hearing, 38*(2), 194-204. doi:10.1097/AUD.0000000000000369

Ronnberg, J., et al. (2013). The Ease of Language Understanding (ELU) model: theoretical, empirical, and clinical advances. *Frontiers in Systems Neuroscience, 7*, 31. doi:10.3389/fnsys.2013.00031

Salthouse, T. A. (2000). Aging and measures of processing speed. *Biol Psychol, 54*(1-3), 35-54.

Saunders, G. H., & Cienkowski, K. M. (1997). Acclimatization to hearing aids. *Ear and Hearing, 18*(2), 129-139.

Song, J. E., et al. (2011). Long-term effects of hearing aids on word recognition scores. *Annals of Otology, Rhinology and Laryngology, 120*(5), 314-319. doi:10.1177/000348941112000506

Stenfelt, S., & Ronnberg, J. (2009). The signal-cognition interface: interactions between degraded auditory signals and cognitive processes. *Scandinavian Journal of Psychology, 50*(5), 385-393. doi:10.1111/j.1467-9450.2009.00748.x

Stone, M. A., & Moore, B. C. (1999). Tolerable hearing aid delays. I. Estimation of limits imposed by the auditory path alone using simulated hearing losses. *Ear and Hearing, 20*(3), 182-192.

Stone, M. A., et al. (2008). Tolerable hearing aid delays. V. Estimation of limits for open canal fittings. *Ear and Hearing, 29*(4), 601-617. doi:10.1097/AUD.0b013e3181734ef2

Taylor. (2006). Real-world satisfaction and benefit with open-canal fittings. *Hearing Journal, 59*(11), 74-82.

Taylor, & Mueller, G. (2016). *Fitting and dispensing hearing aids* (2nd ed.): Plural Publishing.

Taylor, K. S. (1993). Self-perceived and audiometric evaluations of hearing aid benefit in the elderly. *Ear and Hearing, 14*(6), 390-394.

Turner, C. W., & Bentler, R. A. (1998). Does hearing aid benefit increase over time? *Journal of Acoustical Society of America, 104*(6), 3673-3674.

Turner, C. W., & Cummings, K. J. (1999). Speech audibility for listeners with high-frequency hearing loss. *American Journal of Audiology, 8*(1), 47-56. doi:10.1044/1059-0889(1999/002)

Vaillancourt, V., et al. (2008). The Canadian French hearing in noise test. *International Journal of Audiology, 47*(6), 383-385. doi:10.1080/14992020802055300

Vaillancourt, V., et al. (2005). Adaptation of the HINT (hearing in noise test) for adult Canadian Francophone populations. *International Journal of Audiology, 44*(6), 358-369.

van Buuren, S. (2018). *Flexible Imputation of Missing Data, Second Edition*: CRC Press.

Ventry, I. M., & Weinstein, B. E. (1982). The hearing handicap inventory for the elderly: a new tool. *Ear and Hearing, 3*(3), 128-134.

Weschler, D. (1939). *The measurement of adult intelligence*. Baltimore.

Winkler, A., et al. (2016). Open Versus Closed Hearing-Aid Fittings: A Literature Review of Both Fitting Approaches. *Trends in Hearing, 20*. doi:10.1177/2331216516631741

Wu, Y. H., et al. (2016). Psychometric Functions of Dual-Task Paradigms for Measuring Listening Effort. *Ear and Hearing, 37*(6), 660-670. doi:10.1097/AUD.0000000000000335

Yund, E. W., et al. (2006). Acclimatization in wide dynamic range multichannel compression and linear amplification hearing aids. *Journal of Rehabilitation Research and Development, 43*(4), 517-536.

Reference notes

Note 1: As per personal communication with Christian Giguère on July 2019.

Chapter 6- General discussion

The first objective of this thesis was to conduct a systematic review on acclimatization to HAs. The study sought to answer two research questions:

1. Do previous studies confirm the presence of an acclimatization effect among adults with HL following bilateral fitting of HAs?
2. If so, what is the time-course and magnitude of the acclimatization effect?

Results of both questions are discussed.

The second objective of this study was to conduct a longitudinal study to measure the effect of acclimatization to HAs by OAs through two outcome measures: (a) speech-recognition-in-noise performance and (b) listening effort expended to understand speech in noise. Results are discussed for each outcome measure.

Findings from the systematic review on acclimatization

Presence and magnitude of acclimatization effect following hearing aid use

Robinson and Summerfield (1996) reported that acclimatization can occur in two phases. First, self-reported and behavioural improvement represent an improvement in speech and sound perception related to the new auditory stimulation. Second, long-term benefits can be observed with physiological outcomes as a measure of neural reorganization (Gatehouse, 1989). Results from the overall quantitative assessment and the meta-analysis confirmed an acclimatization effect following bilateral HA fitting as determined by self-reported, behavioural and electrophysiological measures.

The largest effect sizes were observed through self-reported outcomes. New HA users tend to report improvement in ease of communication (+11%), better speech understanding in noise (+6%) and in reverberant environment (+9%), reduced aversiveness to background noise (+

22%) and increased global satisfaction of HAs (+2%; Karawani, Jenkins, & Anderson, 2018; Laperuta & Fiorini, 2012). It could be argued that self-reported data is not a direct indicator of an auditory acclimatization or that it exaggerates the acclimatization effect. As reported by Gatehouse (1990), self-reported hearing disability is influenced by personality and verbal and non-verbal IQ. Self-reported ratings have been criticized. According to Leising, Locke, Kurzius, and Zimmermann (2016), participants tend to provide socially desirable answers and self-reported measures should be taken with caution. Nonetheless, self-assessment of HA benefit is essential, as it informs the hearing health professional or the investigator of the ecological potential of acclimatization to HAs. If acclimatization results in an improvement of auditory abilities over time, it is critical for the HA user to perceive these benefits in their everyday life.

Behavioural findings also supported an acclimatization effect by evaluating the improvement of different speech abilities. For speech recognition in quiet, improvement was noted mostly at lower input levels (+32% when the speech stimuli were presented at 50 dB SPL). Significant improvement in speech-recognition-in-noise performance, when measured in percent correct scores, was around 2-3% compared to experienced HA users (Stecker et al., 2006; Yund & Buckles, 1995). This small improvement contributes to the explanation for the non-significant results reported by some investigators (Dawes, Munro, Kalluri, & Edwards, 2014a; Saunders & Cienkowski, 1997). When speech recognition in noise was measured by means of the SNR needed for a fixed performance of 50%, improvement was between 2 and 3 dB (Dawes & Munro, 2016; Karawani et al., 2018). Taylor and Mueller (2016) report that an improvement of 1 dB SNR at a fixed performance of 50% yields an improvement score of approximately 10% (depending on the slope of the psychometric function). Consequently, an improvement of 2 to 3 dB SNR is not consistent with results obtained from percent correct answers because it would represent a 20 to 30% improvement. It should be noted that the study that measured a 2 dB SNR improvement was a randomized control trial that controlled for daily HA use and was the only study of high scientific quality included in the systematic review. Furthermore, Dawes and Munro (2016) found a 3 dB SNR improvement only for a subgroup of participants who wore their HAs for at least 6 hours per day. Both studies included a control group. The two studies which noted a 2-3% improvement on speech recognition in noise had no control groups of experienced HA users and gave no information on HA use (Stecker et al., 2006; Yund & Buckles, 1995). Hence, scientific evidence from Karawani et al. (2018) and Dawes and Munro (2016) is of better quality and more reliable.

Improvement in speech recognition in quiet and in noise was mainly observed in the aided conditions. Because auditory acclimatization is referred to as an improvement in auditory performance provided by acoustic stimulation (Arlinger et al., 1996), it is expected that a change in performance should only be observed for experimental conditions in which the individual can benefit from the acoustic information (i.e., improved audibility).

In terms of dichotic listening, both studies showed that improvement was more noticeable in the non-dominant ear (up to 14%), compared to the dominant ear (7%; Lavie, Attias, & Karni, 2013; Pinheiro, Iorio, Miranda, Dias, & Pereira, 2012). These results suggest that regular HA use can improve binaural integration. Previous studies reported that higher level of performance is observed for the signals presented in the right ear (Davidson & Hugdahl, 1996). This increased performance is referred to as the *right-ear advantage*. This asymmetry is due to a left-hemisphere superiority for speech and language processing (James et al., 2015; Prete, D'Anselmo, Brancucci, & Tommasi, 2018; Tervaniemi & Hugdahl, 2003). It is unclear why the acclimatization effect was greater in the non-dominant ear. One hypothesis would be that there was more room for improvement because the initial performance was lower than for the dominant ear. More research is needed to confirm this theory.

Only one study included in the systematic review investigated the impact of HA use on loudness scaling and discrimination limen for intensity (DLI) performance (Philibert, Collet, Vesson, & Veuillet, 2005). Results indicated a change in loudness perception for sounds initially categorized as “OK”, “loud” and “very loud” at 2 kHz. Therefore, acoustic stimulation provided by HA use increases a listener’s dynamic range by approximately 5.5 dB SPL. Moreover, performances on the DLI task improved significantly after HA use, particularly at 2 kHz and for loud auditory stimuli (+1.45 dB SPL). For both psychoacoustic measures, significant improvements were mostly observed at 2 kHz compared to 0.5 kHz. Participants included in this study were OAs with high frequency HL and the gain provided by the HAs in low frequency bands was significantly less than the gain provided at 2 kHz. Hence, results support the theory that the acclimatization effect occurs mostly in frequency bands where gain is provided by the HAs.

For self-reported and behavioural outcomes, it is important to mention that acclimatization to HAs is dependent of HA use. As seen in studies by Dawes and Munro (2016) with speech-in-noise performances, and by Vestergaard (2006) with self-reported measures, significant improvement was only observed for subgroups of participants wearing their HAs for at least 6 and 4 hours per day, respectively. The results of the meta-analysis shown in Tables 4.5. and 4.6. reveal a significantly larger effect size for both modified groups.

The presence of an acclimatization effect following HA fitting as measured by electrophysiological measures is unclear. Habicht, Finke, and Neher (2018) did not find any acclimatization effect when either wave amplitude or latency were analyzed. Unfortunately, results from this study could not be included in the quantitative analyses and the meta-analyses, because the relevant data were not presented in the article. The conclusion drawn from the two studies using electrophysiological measures included in the systematic review reveal a neural plasticity following HA use (Karawani et al., 2018; Philibert et al., 2005). However, the results were divergent in some ways. Using the frequency-following response (FFR) technique, Karawani et al. (2018) suggest that rather than an auditory acclimatization effect, HA use delays the onset of an auditory deprivation effect (Karawani et al., 2018). On the other hand, Philibert et al. (2005) suggest that the reduced latency of wave V in auditory brain response (ABR) recordings for new HA users is correlated to a neural reorganization following an acclimatization to HAs. Many differences in the designs of the two studies that used electrophysiological measures may explain the discrepancies in the results reported by the investigators. First, Philibert et al. (2005) did not include a control group of experienced HA users. It is impossible to associate the reduced latency to a direct effect of auditory acclimatization and not to other uncontrolled variables. Another limit of this study is that only five new HA users participated in the electrophysiological part of the experiment. A larger sample may have given more robust results. Additionally, the electrophysiological measures are difficultly comparable between studies. The FFR technique is generally used to measure brainstem response to auditory stimulation and has the advantage to be evoked by stimuli of longer duration than the signals used to measure the ABR (Billings, 2013).

However, Coffey, Musacchia, and Zatorre (2017) reported that FFR has a cortical contribution and may be influenced by higher-level cognitive functions. On the other hand, ABR is a more precise way to evaluate the status of the auditory brainstem activity (Song, Nicol, & Kraus, 2011).

The magnitude of acclimatization is difficult to establish with electrophysiological measures because of the discrepancies in results of the studies included in the systematic review. Results from Philibert et al. (2005) showed a reduction of 0.19 ms in wave V latency, specifically in the right ear, while no significant change was observed for the new HA users in the study by Karawani et al. (2018). In terms of amplitude of the electrophysiological measures, once again the results were inconsistent. Philibert et al. (2005) indicated a non-significant change in amplitude of ABR measures. On the other hand, Karawani et al. (2005) argued that, for the 65 dB SPL stimulus condition, the reduction in F0 amplitude of 0.001 to 0.002 μV was attributable to an acclimatization effect. One could have expected the amplitude to increase with HA experience. The authors suggest that the exaggerated response before the use of HA is due to an imbalance of inhibitory and excitatory transmission, which leads to greater excitability in response to suprathreshold stimulation (Karawani et al., 2018).

Although not included in the systematic review, some studies investigated the effect of acclimatization to HAs through electrophysiological measures with unilateral HA users and used the unaided ear as a control. Results from these investigations are scarce. For example, Dawes et al. (2014b) found no observable acclimatization effect in late auditory evoked potentials, while Bertoli, Probst, and Bodmer (2011) found a significant increase of P2 amplitude in the aided ear compared to the unaided ear. In addition, McCullagh (2009) noted that the only change observed in the central auditory system following auditory acclimatization was a reduced latency of N1. Consequently, while acclimatization to HAs does occur, the plasticity in the central auditory system remains unclear. More research is needed to fully understand the neural reorganization following auditory acclimatization to HAs.

Overall, there is a wide variety of self-reported measures, behavioural tests and electrophysiological techniques used to measure acclimatization. It is important to understand the impact of HA use in everyday life situations, on different auditory abilities and at different locations in the central auditory pathway. More research is needed to fully understand the influence of HA use among individuals with HL.

Time-course of the acclimatization effect

From behavioural measures, time-course was determined to be of at least 1 month following HA fitting (see discussion in Chapter 4 for a more detailed explanation).

For self-reported measures, significant improvement was found in two studies (Karawani et al., 2018; Laperuta & Fiorini, 2012) and in one study with a sub-group of participants who used their HAs at least 4 hours per day (Vestergaard, 2006). Karawani et al. (2018) found significant self-reported HA outcomes in all subscales of the Abbreviated Profile of Hearing Aid Benefit (APHAB) and self-reported speech processing through the Speech, Spatial and Qualities of Hearing Scale (SSQ) questionnaire 6 months after HA fitting. Laperuta and Fiorini (2012) found a significant improvement of satisfaction with HAs through the Satisfaction with Amplification in Daily Life (SADL) questionnaire after 3 months. Additionally, this positive effect was maintained after 6 months of HA use. No studies measured significant improvement on self-reported measures in a shorter time frame than 3 months. Vestergaard (2006) administered the Hearing Aid Performance Questionnaire (HAPQ), the International Outcome Inventory for Hearing Aids (IOI-HA), the Glasgow Hearing Air Benefit Profile (GHABP) and the SADL to the participants of his study. For the subgroup of successful HA users (self-reported HA use of at least 4 hours per day), significant improvement on all four questionnaires was noted after 13 weeks of HA use, but not after 1 and 4 weeks post-fitting. Hence, no inference can be made on the exact onset of self-reported improvement in different everyday life contexts. However, the onset is likely between 1 and 3 months.

Concerning electrophysiological measures, the time-course of acclimatization is difficult to establish. Data presented in the study by Karawani et al. (2018) indicated a delay of deprivation instead of an acclimatization effect. Consequently, no information on time-course of acclimatization effect was proposed. In Philibert et al. (2005), electrophysiological measures were obtained before and after 3 and 6 months of HA use. The investigators found a significant reduction of wave V latency after 6 months, but did not mention if the changes in latency between 0 and 3 months were significant. Results from this study suggest that neural reorganization following HA acclimatization can take up to 6 months, but no information was provided on onset of this reorganization. More research is needed to understand the time-course of neural plasticity at different levels of the central auditory pathway following HA use.

This systematic review provided considerable information on the presence of an acclimatization effect, and on the magnitude and time-course of this effect. This review also highlighted the wide variety of outcome measures and test material used among published studies on acclimatization to HAs. Also, as noted above, the scientific quality of evidence of the studies included in the review was generally poor. Finally, important factors such as HA use, inclusion of a control group comprised of experienced HA users and REIG measures should be considered in future studies.

Findings from experimental research on hearing aid acclimatization

The experimental design was developed in order to eliminate shortcomings detected in previous studies on acclimatization to HAs. First, a longitudinal repeated measure design was chosen in order to associate the direct effect of improvement on outcome measures to an acclimatization effect. Second, only bilateral fittings were provided to participants to avoid any deprivation effect in an unaided ear. Third, a control group of experienced HA users was included to detect and eliminate a possible carry-over effect. Fourth, objective data on HA use was obtained through data logging to ensure that any improvements observed could be attributed to acoustic experience. Fifth, REIG measures were obtained from all participants in order to guarantee that all individuals with HL received sufficient gain from their HAs. Finally, to ensure the validity of results, only test materials shown to have acceptable psychometric properties were used for speech recognition in noise and listening effort outcomes.

Findings from behavioural measures

Magnitude and time-course of acclimatization effect following hearing aid use

Results from this study support the hypothesis of a gradual improvement on speech recognition in noise following HA fitting, consistent with an acclimatization effect. Improvement was on average 2 dB SNR for new HA users after 1 month of HA use. No significant change in performance was observed for experienced HA users. These findings are consistent with results from previous studies using a SNR required for a 50% correct answer performance once HA use was over 6 hours per day (Dawes & Munro, 2016; Karawani et al., 2018). For a more complete discussion on magnitude and time-course of acclimatization as measured by behavioural measures, see discussion in Chapter 5.

Influence of noise reduction algorithms and directional microphones

One might have thought that complex signal processing could delay the time-course of the adaptation to new auditory cues. However, results from this study do not indicate that NRAs and DMs influenced the acclimatization period. Although not significant, there is a slight tendency for the NRA- and DM-activated group to achieve the maximum improvement with a delayed time-course compared to the group without NRA and DM. It is possible that a larger sample of participants would have revealed a significant delay. A post-experiment power analysis revealed that a total sample size of 92 (46 participants in each group of NRA and DM activation option) would have been needed to provide at least 80% power to detect a small effect size (f=0.100; based on results of the within-between analysis of variance with an α level of 0.05). Moreover, the Oticon software does not provide information on the percentage of time that the NRAs and DMs are activated in everyday life. If a participant was included in the NRA- and DM-activated group but had a calm lifestyle without much background noise, it is possible that the HA user did not experience much of the complex signal processing provided by these technologies.

It would be of interest to investigate the separate effect of each HA technology on the acclimatization effect. Future research should attempt to have bigger sample sizes and to investigate the influence of DMs and NRAs on acclimatization separately.

Influence of daily hearing aid use

In this study, daily HA use was not correlated with the magnitude and time-course of the acclimatization effect. This is in contrast with results from the systematic review, which found that the primary factor influencing the acclimatization effect was HA use. However, because participants wore their HAs on average 12 hours per day, it is likely that a minimum amount of HA use is sufficient to favour acclimatization to HAs and does not influence the magnitude and time-course of the improvement.

Influence of baseline performance on speech perception-in-noise test

As seen in Chapter 5, the degree of HL is significantly correlated with the magnitude of acclimatization ($r = 0.354$, $p = 0.047$). Speech recognition in noise is a complex task that relies not only on peripheral hearing, but also on different processing levels such as central auditory system and cognitive abilities. Consequently, the influence of baseline performance of speech recognition in noise was investigated.

A stepwise regression analysis was conducted to measure the proportion of variance in the amount of acclimatization effect (i.e., improvement of performance on a speech perception-in-noise task between ES1 and ES7) explained by the degree of HL and baseline performance on the HINT_{FC}. For this analysis, two independent variables were considered: (a) performance on the speech-in-noise test at the initial testing session and (b) severity of HL as calculated by the pure tone average (PTA) of hearing sensitivity thresholds at 500, 1,000 and 2,000 Hz. Those frequencies were chosen because they best reflect the specificities of the frequency spectrum in the HINT_{FC} (see Note 1).

Absence of violation of the assumptions of normality, linearity, multicollinearity and homoscedasticity was confirmed with preliminary analyses. The chosen model included only the initial performance, explaining 42.4% of the variance ($F[1,30] = 22.117$, $p < 0.001$). The severity of HL was excluded from the model as it did not contribute any additional information ($p = 0.366$).

Consequently, both variables account for a common amount of variance in the magnitude of the acclimatization effect, with baseline performance on the speech-recognition-in-noise test being the most important. In accordance with this analysis, the two participants who performed the best during the initial test session displayed a reduction in performance on the speech-in-noise test (increase of SNR) over time. As seen in Table 6.1., the baseline performance for these two participants are outside the 95% confidence interval for the average initial performance of new HA users.

Table 6.1.*Speech-in-noise performance (SNR) at week 0 (ES1)*

Participants	Average SNR performance at ES1 (z score)	95% confidence interval	Baseline performance of participants whose performance decreased over time (SNR)
NHAU, NRA ON	1.375	-2.535 to 5.286	-3
NHAU, NRA OFF	1.733 (1.334)	-0.882 to 4.348	-1

Therefore, acclimatization effect will occur if the individual presenting a HL has a sufficiently poor initial performance in noise. If the individual already has a good speech-perception-in-noise performance before the acclimatization period, a ceiling effect may be reached and improvement may not be measurable.

Influence of cognitive abilities

Working memory and speed of processing did not correlate with the magnitude of the acclimatization effect. Results suggest that cognitive abilities do not have a significant effect on the capacity to adapt to HAs. Despite the results from the current study, some limitations in the chosen tests could explain the absence of correlation between cognitive abilities and the acclimatization effect. The RST was chosen to minimize the effect of HL on the measurement of working memory (see Besser, 2013, for a review). However, individual differences in ease of reading comprehension may have affected the specificity of the test (Daneman & Carpenter, 1980). Specifically, good readers have more efficient reading processing and better scores on the RST. The higher scores are then interpreted as better working memory while being ultimately related to an ease of reading. Furthermore, large interindividual variability was observed and may have obscured small associations.

The DSST was initially developed as a tool in a test battery to measure adult intelligence (Weschler, 1939). It is still widely used because it is brief, reliable and not impacted by education or language (Jaeger, 2018). While the DSST is a sensitive measure of speed of processing, it is not a specific measure of this ability. Lezak (1995) suggests that the DSST performance is an association of "complex attention", while Darby (2005) mentions that this test measures visual perception, and fine manual motor and mental functions. Also, Laux (1985) suggests that the DSST correlates with verbal abilities. The lack of specificity of the DSST could explain the fact that performances did not correlate with the acclimatization effect. Salthouse & Madden (2008) suggest using multiple measures of speed of processing, because the DSST is not a "process-pure" measure.

In future research, to minimize the influence of ease of reading comprehension on the RST and to control for the lack of specificity of the DSST, a combination of test measures should be considered. For example, a working memory test measure for which it's construct validity was confirmed is the Word auditory recognition and recall measure (WARRM; Smith et al., 2016). The WARRM presents, in an auditory modality, a sentence with a target word and the participant is asked to repeat the target word and make a judgment about whether the first letter of the word is between A and M or between N and Z in the alphabet list. An additional benefit of the WARRM is that it also yields a word recognition accuracy score which can be useful to evaluate the influence of HL on the working memory result. As suggested by Cepeda, Blackwell and Munakata (2013), to accurately measure speed of processing, simple test measures should be used, such as the horizontal line making test (Salthouse, 1993) or the digit copying test (Weschler, 1991).

Working memory and speed of processing were also assessed at the end of the study period (10-month post-HA fitting). This allowed an additional analysis on whether HA use improved cognitive abilities of new HA users. The experimental design was not developed to answer this question. In order to validate a direct effect of HA use on cognitive abilities, a control group of non-HA users would have been important. However, for the purpose of this analysis, experienced HA users were used to control for possible carry-over effect. Results showed no improvement of working memory capacity after HA use ($F[1,41] = 0.386$, $p = 0.538$). However, an improvement of speed of processing ($F[1,41] = 6.919$, $p = 0.012$) was noted. It is possible that the improvement in speed of processing is attributable to a practice effect, because it was also present for experienced HA users, as corroborated by a non-significant interaction between groups ($F[1,41] = 2.946$, $p = 0.094$). This is in accordance with previous study that reported a test retest improvement attributable to a practice effect (Jaeger, 2018). Although more research is needed, using an experimental design better suited to answer this question, this study does not support the hypothesis that HA use improves cognitive abilities, after 10 months of HA use.

Findings from listening effort measures

Findings from the longitudinal study do not support the hypothesis that the listening effort needed to understand speech in noise decreases over time due to HA acclimatization. The unchanged listening effort suggests that cognitive and attentional resources deployed by HA users remained the same for at least 38 weeks post-HA fitting. No previous longitudinal study investigated the effect of auditory acclimatization on listening effort. However, in a cross-sectional study, using an eye tracking paradigm to measure reaction time, Habicht, Kollmeier, and Neher (2016) found that experienced HA users could process noisy speech more rapidly than new HA users when they were tested under a complex linguistic condition. The authors conclude that HA experience can reduce listening effort expended to understand speech in a noisy environment. Results from Habicht et al. (2016) are to be taken with caution because in a cross-sectional study, it is impossible to identify if the shorter response times for the experienced HA users are due to a direct and undeniable effect of HA use or whether it is due to underlying variables. Consequently, future research investigating the effect of HA use on listening effort should use a longitudinal repeated measures design.

Limitations in the listening effort dual-task paradigm may account for the absence of significant acclimatization to HA effect observed in the present study. Considering that the average performance level on the secondary task was near chance performance, it is possible that the difficulty of the primary task combined with the difficulty of the secondary task made the experiment too difficult for the participants to be able to perform well when both tasks were administered concurrently. Wu, Stangl, Zhang, Perkins, and Eilers (2016) measured listening effort with a dual-task paradigm using the HINT as the primary task and the RT on the secondary task as the dependent variable portraying listening effort. The results of this experiment revealed longer RTs (more listening effort expended) when the SNR was set to yield performance levels ranging from 30 to 50% correct scores (Wu et al., 2016). According to the investigators, shorter RTs were obtained when unfavourable SNRs were used, yielding performance levels below 30% correct answers. There is experimental evidence to suggest that when the task is too taxing, participants experience cognitive overload and tend to give up (Petersen, Wostmann, Obleser, Stenfelt, & Lunner, 2015; Wu et al., 2016). In the present study, SNRs were fixed for a speech intelligibility of 50% which, when combined with the secondary task, may have made the experimental task too taxing under the dual-task condition. Participants were asked to answer the speech-recognition task first, which probably required considerable attentional and cognitive resources. It is possible that no residual resources were available to perform the secondary task and thus, the participants disengaged themselves from the secondary task. In future studies on acclimatization to HAs, it would be important to conduct extensive pilot tests to ensure that, when administered concurrently, the primary task and the secondary task are not too difficult (nor too easy), so that a dual-task cost can be measured.

Limits of this thesis

As mentioned earlier, the difficulty level of the combination of both tasks included in the dual-task paradigm may have been too difficult to efficiently measure an improvement of listening effort. Previous studies used the same type of stimuli for the secondary task to successfully measure listening effort (Anderson Gosselin & Gagne, 2011; Gosselin & Gagne, 2011). As for the present longitudinal study on acclimatization, both the primary task and the secondary task were presented simultaneously, and participants were asked to answer the speech-in-noise task first and then the TPRT. In previous studies, the primary task was a closed-set sentence-recognition task fixed at an 80% performance level. Not only was the fixed performance set at an easier level but providing a closed-set of answers also made the task easier. In the study reported in Chapter 5, fixed performance was set at a more difficult level (50%) and participants had to repeat the whole sentence orally. The task of answering orally recruits additional working memory and may have made it more difficult to remember the vibrations that were felt (Tirre & Pena, 1992). Moreover, in previous studies, the secondary task was similar to the TPRT described in Chapter 5, but with only with a sequence of two tactile elements vs. a sequence of three tactile elements. The additional vibration increased the attentional and cognitive resources needed to remember the vibration sequence. Consequently, even if the participants could successfully perform both tasks separately, once combined, it became too difficult. Additionally, they were instructed to give priority, in terms of performance, to the primary task. Hence, all participants had to choose only one task to direct their resources towards.

Another limit of the study presented in Chapter 5 of this thesis is that no self-reported measures of acclimatization to HAs were included. The systematic review revealed that the largest effect size in favour of an acclimatization effect was measured through self-reported outcomes, such as the SSQ and the subcategories of the APHAB. It would have been interesting to investigate whether the improvement on the speech-recognition task in noise in the laboratory setting translated into everyday life situations for participants.

Incidentally, open-canal HAs were chosen because they improve the satisfaction ratings and success rate in OAs with high-frequency HL (Gnewikow & Moss, 2006). All participants presented typical presbycusis resulting in normal or near-normal hearing sensitivity at low frequencies and gradual mild-to-moderately severe HL in higher frequency regions. A recent literature review established that an open-canal fitting reduces occlusion, improves own-voice perception, sound quality and sound localization (Winkler, Latzel, & Holube, 2016). Unfortunately, this type of fitting also comes with disadvantages, such as reduced benefit from NRAs and DMs, less compression, and sound delays in amplified high-frequency sounds (Stone, Moore, Meisenbacher, & Derleth, 2008; Winkler et al., 2016). In this study, the reduced benefits from NRAs and DMs may have reduced the NRA and DM effect on acclimatization to a point where the influence wasn't significant. In future studies on acclimatization, it would be interesting to compare open-canal fittings with closed-canal fittings, which optimize the benefits from NRAs and DMs.

Clinical implication

Results presented in this thesis have an important clinical implication. Not only do the results confirm that new HA users need time to adapt to new acoustic stimulations, but also that it is essential to wear the HAs at least 4 to 6 hours per day to fully benefit from this acclimatization. Clinicians now have concrete scientific evidence on the importance of HA use in order to reach the full acclimatization effect. It is suggested that hearing health care professionals should verify their clients' datalogging. This will make it possible to associate the level of HA use with the type and amount of remaining difficulties they may have adapting to their HAs. For example, if a patient comes back a month after the initial fitting with residual difficulties, such as understanding conversations in a restaurant, the audiologist or hearing health clinician may want to confirm that the patient is actually wearing the HAs at least 4 to 6 hours per day.

The main complaint about HAs is the difficulty understanding speech in noise and the annoyance of background noise. Results from the longitudinal study on acclimatization presented in Chapter 5 reveal that, for speech-recognition-in-noise performance, improvement is on average about 2 dB SNR (which may represent more than 20% improvement) over a period of 1 month post-HA fitting. It would be advisable for clinicians to offer a trial period of at least 2 months, because some individuals may need more time to fully adapt to their HAs. Additionally, the clinician should include a speech-in-noise test to their evaluation test battery, in order to have a better idea of the patient's potential for improvement. The better they perform, the smaller the acclimatization effect will be. This information allows the clinician to have a counselling approach directed towards the patients' needs and abilities.

It is quite possible that after the acclimatization period, OAs with HL still experience hearing-related activity limitations and participation restrictions. Additional rehabilitation services should be offered to the individuals with HL in conjunction with the use of HAs. Communication programs that target enhancement of speech perception abilities and communication, using strategies such as lipreading and stress management (Gagné & Jennings, 2008), have been proven successful (Hawkins, 2005; Hickson et al., 2006). A critical review of rehabilitation interventions by Laplante-Levesque, Hickson, and Worrall (2010) reported that even if HAs, hearing assistance technology and communication programs are valuable, two changes to current practice should be applied in order to improve uptake and adherence to rehabilitation services. First, access to rehabilitation intervention programs should be optimized. Davis et al. (2007) suggest that systematic hearing screenings for individuals from 55 to 74 years of age be implemented to increase awareness to HL. Following the implementation of a hearing screening procedure, an adequate referral system should be in place (Laplante-Levesque et al., 2010). In addition to HAs, if audiologists or hearing health professionals offer a range of rehabilitation services, OAs with HL will be more likely to take up and adhere to auditory rehabilitation. The second change that should be applied is to actively include OAs in the decision-making process. The shared decision process model has shown to increase the willingness of OAs to make health-related behavioural changes (Laplante-Levesque et al., 2010; Montori, Gafni, & Charles, 2006).

Overall, although benefits provided by HAs can significantly increase over time, it is important for clinicians to propose a comprehensive range of rehabilitation services and to share the decision-making process. If HAs are retained as an option, a trial period should be offered and counselling on HA use and potential benefits should be offered.

Future direction

This thesis supports the presence of an acclimatization effect to HAs by OAs. However, many questions remain unanswered. First, more research is needed to fully understand the influence of HA acclimatization on neural reorganization. Because cortical reorganization has previously been associated with poorer speech-recognition-in-noise performance (Campbell & Sharma, 2014), it would be interesting to expand this association to acclimatization-related improvement on speech-in-noise performance and neural reorganization. More studies are needed that explore this association using electrophysiological measures in longitudinal study designs. Consequently, the effect of neural reorganization on latency and amplitude at different levels of the central auditory pathways could be understood.

Second, the influence of acclimatization to HAs on listening effort is still unknown. It is possible that, although no further improvement of performance is noted after 1 month post-HA fitting, new HA users continue to acclimatize so that less attentional and cognitive resources are needed to understand speech under difficult listening conditions. Future research could use a dual-task paradigm with less attentional and cognitive resources needed or use physiological tests to procure measures of listening effort. Recent studies have shown that pupil dilatation is a reliable and sensitive technique to measure listening effort (Zekveld, Kramer, & Festen, 2011). Koelewijn, de Kluiver, Shinn-Cunningham, Zekveld, and Kramer (2015) used pupil dilatation to measure the relationship between location uncertainty and listening effort. Results show that an increased cognitive demand is associated with a larger pupil dilatation response. Future research could use this technique to investigate HA acclimatization.

Third, it would be beneficial to understand the influence of auditory training on the acclimatization effect. Auditory training is defined as a "purposeful and systematic presentation of sounds such that listeners are taught to make perceptual distinctions about those sounds" (Olson, 2015, p. 285). There is evidence that auditory training improves speech-recognition performance and improves HA satisfaction (Burk & Humes, 2008; Henshaw & Ferguson, 2013). Stecker et al. (2006) investigated the effect of the perceptual training of syllable identification in noise on speech-perception-in-noise performance as measured by the NST. Investigators found a beneficial effect of auditory training on speech perception for new and experienced HA users. Consequently, it is likely that auditory training may improve the magnitude of the acclimatization effect. If so, training programs should be developed, be easily accessible and be user-friendly. Further research is needed to define the dimensions of training that should be addressed to optimize benefits.

Chapter 7- Conclusion

In conclusion, results from this thesis support an acclimatization effect following HA use. Both studies confirm an acclimatization effect as measured by behavioural measures. More specifically, the systematic review revealed that new HA users can improve speech-recognition-in-noise performance by as much as 2 - 3 dB SNR over a period of one month. Concurring with these results, the longitudinal study determined that participants reached a maximum improvement of 2 dB SNR 1 month after HA fitting. Moreover, results from the systematic review indicate that self-reported questionnaires and physiological measures are also efficient methods to determine the effect of acclimatization to HAs. The systematic review documented the wide variety of test materials used across studies and the generally low quality of scientific evidence. Measures of listening effort in the longitudinal study showed no improvement over time after HA fitting. Either acclimatization to HAs has no effect on listening effort, or methodological issues interfered with the measurement of an actual decrease of listening effort following HA use.

Considering that the time-course of the acclimatization effect takes place over a period of one-month (minimally), a trial period of more than one month is advised. A strong association was also found between HA use and effect size of acclimatization. Consequently, most participants who wore their HAs for at least 4 to 6 hours per day benefited from an acclimatization effect. This information is important and useful for hearing health professionals when they provide informational counselling to their clients. Prior to HA recommendation or HA fitting, it is also advised to conduct a measure of the patients' speech-recognition-in-noise ability, because results of the longitudinal study established a strong correlation between baseline performance on the HINT_{FC} and magnitude of the acclimatization effect. It is likely that participants with poorer initial performances have more room for improvement.

Finally, considering that improvement of speech-recognition-in-noise performance ranges from 2 to 3 dB SNR, which represents approximately a 20 to 30% performance gain, residual difficulties may remain even after optimal acclimatization to HAs. It is important for audiologists to offer a wide range of rehabilitation interventions and to combine these interventions with HA recommendation.

References

Aazh, H., Prasher, D., Nanchahal, K., & Moore, B. C. (2015). Hearing-aid use and its determinants in the UK National Health Service: a cross-sectional study at the Royal Surrey County Hospital. *International Journal of Audiology, 54*(3), 152-161. doi:10.3109/14992027.2014.967367

Amariglio, R. E., Becker, J. A., Carmasin, J., Wadsworth, L. P., Lorius, N., Sullivan, C., . . . Rentz, D. M. (2012). Subjective cognitive complaints and amyloid burden in cognitively normal older individuals. *Neuropsychologia, 50*(12), 2880-2886. doi:10.1016/j.neuropsychologia.2012.08.011

Anderson, D. L., & Noble, W. (2005). Couples' attributions about behaviours modulated by hearing impairment: links with relationship satisfaction. *International Journal of Audiology, 44*(4), 197-205. doi:10.1080/14992020500057699

Anderson Gosselin, P., & Gagne, J. P. (2011). Older adults expend more listening effort than young adults recognizing speech in noise. *Journal of Speech, Language and Hearing Research, 54*(3), 944-958. doi:10.1044/1092-4388(2010/10-0069)

Arlinger, S. (2003). Negative consequences of uncorrected hearing loss—a review. *International Journal of Audiology, 42 Suppl 2*, 2S17-20. Retrieved from https://www.ncbi.nlm.nih.gov/pubmed/12918624

Arlinger, S., Gatehouse, S., Bentler, R. A., Byrne, D., Cox, R. M., Dirks, D. D., . . . Willott, J. F. (1996). Report of the Eriksholm Workshop on auditory deprivation and acclimatization. *Ear and Hearing, 17*(3 Suppl), 87S-98S. doi:10.1097/00003446-199617031-00009

Baltes, P. B., & Lindenberger, U. (1997). Emergence of a powerful connection between sensory and cognitive functions across the adult life span: a new window to the study of cognitive aging? *Psychology and Aging, 12*(1), 12-21. doi:10.1037//0882-7974.12.1.12

Barker, A. B., Leighton, P., & Ferguson, M. A. (2017). Coping together with hearing loss: a qualitative meta-synthesis of the psychosocial experiences of people with hearing loss and their communication partners. *International Journal of Audiology, 56*(5), 297-305. doi:10.1080/14992027.2017.1286695

Barker, F., Mackenzie, E., Elliott, L., Jones, S., & de Lusignan, S. (2014). Interventions to improve hearing aid use in adult auditory rehabilitation. *Cochrane Database of Systematic Reviews* (7), CD010342. doi:10.1002/14651858.CD010342.pub2

Bentler, R., & Chiou, L. K. (2006). Digital noise reduction: an overview. *Trends in Amplification, 10*(2), 67-82. doi:10.1177/1084713806289514

Bentler, R. A. (2005). Effectiveness of directional microphones and noise reduction schemes in hearing aids: a systematic review of the evidence. *Journal of the American Academy of Audiology, 16*(7), 473-484. doi:10.3766/jaaa.16.7.7

Bertoli, S., Probst, R., & Bodmer, D. (2011). Late auditory evoked potentials in elderly long-term hearing-aid users with unilateral or bilateral fittings. *Hearing Research, 280*(1-2), 58-69. doi:10.1016/j.heares.2011.04.013

Billings, C. J. (2013). Uses and Limitations of Electrophysiology with Hearing Aids. *Seminars in Hearing, 34*(4), 257-269. doi:10.1055/s-0033-1356638

Blamey, P. J., Fiket, H. J., & Steele, B. R. (2006). Improving speech intelligibility in background noise with an adaptive directional microphone. *Journal of the American Academy of Audiology, 17*(7), 519-530. doi:10.3766/jaaa.17.7.7

Blauert, J. (2005). *Communication acoustics* (J. Blauert Ed.). Berlin, Germany: Springer.

Brebion, G. (2001). Language processing, slowing, and speed/accuracy trade-off in the elderly. *Experimental Aging Research, 27*(2), 137-150. doi:10.1080/036107301750073999

Brons, I., Houben, R., & Dreschler, W. A. (2014). Effects of noise reduction on speech intelligibility, perceived listening effort, and personal preference in hearing-impaired listeners. *Trends in Hearing, 18*. doi:10.1177/2331216514553924

Brooks, D. N., Hallam, R. S., & Mellor, P. A. (2001). The effects on significant others of providing a hearing aid to the hearing-impaired partner. *British Journal of Audiology, 35*(3), 165-171. doi:10.1080/00305364.2001.11745234

Burk, M. H., & Humes, L. E. (2008). Effects of long-term training on aided speech-recognition performance in noise in older adults. *Journal of Speech, Language and Hearing Research, 51*(3), 759-771. doi:10.1044/1092-4388(2008/054)

Byrne, D., & Noble, W. (1998). Optimizing sound localization with hearing aids. *Trends in Amplification, 3*(2), 51-73. doi:10.1177/108471389800300202

Campbell, J., & Sharma, A. (2013). Compensatory changes in cortical resource allocation in adults with hearing loss. *Frontiers in Systems Neuroscience, 7*, 71. doi:10.3389/fnsys.2013.00071

Campbell, J., & Sharma, A. (2014). Cross-modal re-organization in adults with early stage hearing loss. *PLoS One, 9*(2), e90594. doi:10.1371/journal.pone.0090594

Castiglione, A., Benatti, A., Velardita, C., Favaro, D., Padoan, E., Severi, D., . . . Martini, A. (2016). Aging, Cognitive Decline and Hearing Loss: Effects of Auditory Rehabilitation and Training with Hearing Aids and Cochlear Implants on Cognitive Function and Depression among Older Adults. *Audiology & Neuro-otology, 21 Suppl 1*, 21-28. doi:10.1159/000448350

Cepeda, N. J., Blackwell, K. A., & Munakata, Y. (2013). Speed isn't everything: complex processing speed measures mask individual differences and developmental changes in executive control. Developmental science, 16(2), 269–286. https://doi.org/10.1111/desc.12024

CHABA. (1988). Speech understanding and aging. The Journal of the Acoustical Society of America, 83, 859-895.

Chen, H. L. (1994). Hearing in the elderly. Relation of hearing loss, loneliness, and self-esteem. *Journal of Gerontological Nursing, 20*(6), 22-28. doi:10.3928/0098-9134-19940601-07

Chisolm, T. H., Johnson, C. E., Danhauer, J. L., Portz, L. J., Abrams, H. B., Lesner, S., . . . Newman, C. W. (2007). A systematic review of health-related quality of life and hearing aids: final report of the American Academy of Audiology Task Force On the Health-Related Quality of Life Benefits of Amplification in Adults. *Journal of the American Acadademy of Audiology, 18*(2), 151-183. doi:10.3766/jaaa.18.2.7

Chung, K. (2007). Effective compression and noise reduction configurations for hearing protectors. The *Journal of the Acoustical Society of America, 121*(2), 1090-1101. Retrieved from https://www.ncbi.nlm.nih.gov/pubmed/17348531

Coffey, E. B. J., Musacchia, G., & Zatorre, R. J. (2017). Cortical Correlates of the Auditory Frequency-Following and Onset Responses: EEG and fMRI Evidence. *Journal of Neuroscience, 37*(4), 830-838. doi:10.1523/JNEUROSCI.1265-16.2016

Cox, R. M., & Alexander, G. C. (1992). Maturation of hearing aid benefit: objective and subjective measurements. *Ear and Hearing, 13*(3), 131-141. Retrieved from https://www.ncbi.nlm.nih.gov/pubmed/1397752

Dahlquist, M., Lutman, M. E., Wood, S., & Leijon, A. (2005). Methodology for quantifying perceptual effects from noise suppression systems. *International Journal of Audiology, 44*(12), 721-732. Retrieved from https://www.ncbi.nlm.nih.gov/pubmed/16450924

Daneman, M., & Carpenter, P. A. (1980). Individual differences in working memory and reading. *Journal of Verbal Learning and Verbal Behavior, 19*(4), 450-466. doi:https://doi.org/10.1016/S0022-5371(80)90312-6

Darby, D., Walsh, K. (2005). *Neuropsychology* (5th ed.). Melbourne.

Davidson, R. J., & Hugdahl, K. (1996). *Brain asymmetry*: Mit Press.

Davis, A., Smith, P., Ferguson, M., Stephens, D., & Gianopoulos, I. (2007). Acceptability, benefit and costs of early screening for hearing disability: a study of potential screening tests and models. *Health Technology Assessment, 11*(42), 1-294. doi:10.3310/hta11420

Dawes, P., Cruickshanks, K. J., Fischer, M. E., Klein, B. E., Klein, R., & Nondahl, D. M. (2015). Hearing-aid use and long-term health outcomes: Hearing handicap, mental health, social engagement, cognitive function, physical health, and mortality. *International Journal of Audiology, 54*(11), 838-844. doi:10.3109/14992027.2015.1059503

Dawes, P., Emsley, R., Cruickshanks, K. J., Moore, D. R., Fortnum, H., Edmondson-Jones, M., . . . Munro, K. J. (2015). Hearing loss and cognition: the role of hearing aids, social isolation and depression. *PLoS One, 10*(3), e0119616. doi:10.1371/journal.pone.0119616

Dawes, P., & Munro, K. (2016). Auditory distraction and acclimatization to hearing aids. *Ear and Hearing, 38*(2), 174-183.

Dawes, P., Munro, K. J., Kalluri, S., & Edwards, B. (2014a). Acclimatization to hearing aids. *Ear and Hearing, 35*(2), 203-212. doi:10.1097/AUD.0b013e3182a8eda4

Dawes, P., Munro, K. J., Kalluri, S., & Edwards, B. (2014b). Auditory acclimatization and hearing aids: late auditory evoked potentials and speech recognition following unilateral and bilateral amplification. The *Journal of the Acoustical Society of America, 135*(6), 3560-3569. doi:10.1121/1.4874629

Dean, M. R., & McDermott, H. J. (2000). Preferred listening levels: the effect of background noise for moderate-to-profoundly hearing impaired aid users. *Scandinavian Audiology, 29*(3), 139-149. doi:10.1080/010503900750042707

Desjardins, J. L., & Doherty, K. A. (2013). Age-related changes in listening effort for various types of masker noises. *Ear and Hearing, 34*(3), 261-272. doi:10.1097/AUD.0b013e31826d0ba4

Desjardins, J. L., & Doherty, K. A. (2014). The effect of hearing aid noise reduction on listening effort in hearing-impaired adults. *Ear and Hearing, 35*(6), 600-610. doi:10.1097/AUD.0000000000000028

Desmettes, D., Hupet, M., Schelstraete, M. A., & Ven Der Linden, M. (1985). Adaptation en langue française du “Reading Span Test” de Daneman et Carpenter (1980)[French language adaptation of Daneman and Carpenter's Reading Span Test (1980)]. *L’année psychologique, 95*(3), 459-482.

Desmettes, D., Hupet, M., Schelstraete, M.A., Van der Linden, M. (1995). Adaptation en langue française du Reading Span Test de Daneman et Carpenter (1980)[French language adaptation of Daneman and Carpenter's Reading Span Test (1980)]. *L'année psychologique, 95*(3), 459-482. doi:10.3406/psy.1995.28842

Dillon, H. (1996). Compression? Yes, but for low or high frequencies, for low or high intensities, and with what response times? *Ear and Hearing, 17*(4), 287-307. Retrieved from https://www.ncbi.nlm.nih.gov/pubmed/8862967

Dillon, H. (2012). *Hearing aids* (2 ed.). New York, NY, USA: Thieme.

Duijvestijn, J. A., Anteunis, L. J., Hoek, C. J., Van Den Brink, R. H., Chenault, M. N., & Manni, J. J. (2003). Help-seeking behaviour of hearing-impaired persons aged > or = 55 years; effect of complaints, significant others and hearing aid image. *Acta Oto-laryngolica, 123*(7), 846-850. doi:10.1080/0001648031000719

Felipe, L. (2019). The relationship of cognitive function and hearing loss of the elderly in the audiologist field. *Journal of Medical Research and Health Sciences, 2*(2), 540-542. doi:https://doi.org/10.15520/jmrhs.v2i2.30

Ferguson, M. A., Kitterick, P. T., Chong, L. Y., Edmondson-Jones, M., Barker, F., & Hoare, D. J. (2017). Hearing aids for mild to moderate hearing loss in adults. *Cochrane Database of Systematic Reviews, 9*, CD012023. doi:10.1002/14651858.CD012023.pub2

Flynn, M. C., Dowell, R. C., & Clark, G. M. (1998). Aided speech recognition abilities of adults with a severe or severe-to-profound hearing loss. *Journal of Speech, Language and Hearing Research, 41*(2), 285-299. doi:10.1044/jslhr.4102.285

Fortunato, S., Forli, F., Guglielmi, V., De Corso, E., Paludetti, G., Berrettini, S., & Fetoni, A. R. (2016). A review of new insights on the association between hearing loss and cognitive decline in ageing. *Acta Otorhinolaryngolica Italica, 36*(3), 155-166. doi:10.14639/0392-100X-993

Fraser, S., Gagne, J. P., Alepins, M., & Dubois, P. (2010). Evaluating the effort expended to understand speech in noise using a dual-task paradigm: the effects of providing visual speech cues. *Journal of Speech, Language and Hearing Research, 53*(1), 18-33. doi:10.1044/1092-4388(2009/08-0140)

Freitas, S., Prieto, G., Simoes, M. R., & Santana, I. (2015). Scaling Cognitive Domains of the Montreal Cognitive Assessment: An Analysis Using the Partial Credit Model. *Archives of Clinical Neuropsychology*. doi:10.1093/arclin/acv027

Gagné, J.-P., & Jennings, M. B. (2008). *Audiological rehabilitation intervention services for adults with acquired hearing impairment* (2nd ed.). New York: Thieme.

Gagné, J. P., Besser, J., & Lemke, U. (2017). Behavioral Assessment of Listening Effort Using a Dual-Task Paradigm. *Trends in Hearing, 21*, 2331216516687287. doi:10.1177/2331216516687287

Gatehouse, S. (1989). Apparent auditory deprivation effects of late onset: the role of presentation level. The *Journal of the Acoustical Society of America, 86*(6), 2103-2106. doi:10.1121/1.398469

Gatehouse, S. (1990). Determinants of self-reported disability in older subjects. *Ear and Hearing, 11*(5 Suppl), 57S-65S. Retrieved from https://www.ncbi.nlm.nih.gov/pubmed/2148534

Gatehouse, S. (1992). The time course and magnitude of perceptual acclimatization to frequency responses: evidence from monaural fitting of hearing aids. *The Journal of the Acoustical*

Society of America, 92(3), 1258-1268. Retrieved from https://www.ncbi.nlm.nih.gov/pubmed/1401514

Gates, G. A., & Mills, J. H. (2005). Presbycusis. *The Lancet, 366*(9491), 1111-1120. doi:10.1016/S0140-6736(05)67423-5

Gauthier, S., Patterson, C., Gordon, M., Soucy, J. P., Schubert, F., & Leuzy, A. (2011). Commentary on "Recommendations from the National Institute on Aging-Alzheimer's Association workgroups on diagnostic guidelines for Alzheimer's disease." A Canadian perspective. *Alzheimer's & Dementia, 7*(3), 330-332. doi:10.1016/j.jalz.2011.03.006

Gnewikow, D., & Moss, M. (2006). Hearing aid outcomes with open- and closed-canal fittings. *Hearing Journal, 59*(11), 68-70.

Gosselin, P. A., & Gagne, J. P. (2011). Older adults expend more listening effort than young adults recognizing audiovisual speech in noise. *International Journal of Audiology, 50*(11), 786-792. doi:10.3109/14992027.2011.599870

Habicht, J., Finke, M., & Neher, T. (2018). Auditory Acclimatization to Bilateral Hearing Aids: Effects on Sentence-in-Noise Processing Times and Speech-Evoked Potentials. *Ear and Hearing, 39*(1), 161-171. doi:10.1097/AUD.0000000000000476

Habicht, J., Kollmeier, B., & Neher, T. (2016). Are Experienced Hearing Aid Users Faster at Grasping the Meaning of a Sentence Than Inexperienced Users? An Eye-Tracking Study. *Trends in Hearing, 20*. doi:10.1177/2331216516660966

Hallam, R., Ashton, P., Sherbourne, K., & Gailey, L. (2008). Persons with acquired profound hearing loss (APHL): how do they and their families adapt to the challenge? *Health (London), 12*(3), 369-388. doi:10.1177/1363459308090054

Hallgren, M., Larsby, B., Lyxell, B., & Arlinger, S. (2005). Speech understanding in quiet and noise, with and without hearing aids. *International Journal of Audiology, 44*(10), 574-583. doi:10.1080/14992020500190011

Hartley, D., Rochtchina, E., Newall, P., Golding, M., & Mitchell, P. (2010). Use of hearing aids and assistive listening devices in an older Australian population. *Journal of the American Academy of Audiology, 21*(10), 642-653. doi:10.3766/jaaa.21.10.4

Hawkins, D. B. (2005). Effectiveness of counseling-based adult group aural rehabilitation programs: a systematic review of the evidence. *Journal of the American Academy of Audiology, 16*(7), 485-493. doi:10.3766/jaaa.16.7.8

Healy, E. W., Yoho, S. E., Wang, Y., & Wang, D. (2013). An algorithm to improve speech recognition in noise for hearing-impaired listeners. *The Journal of the Acoustical Society of America, 134*(4), 3029-3038. doi:10.1121/1.4820893

Heffernan, E., Coulson, N. S., Henshaw, H., Barry, J. G., & Ferguson, M. A. (2016). Understanding the psychosocial experiences of adults with mild-moderate hearing loss: An application of Leventhal's self-regulatory model. *International Journal of Audiology, 55 Suppl 3*, S3-S12. doi:10.3109/14992027.2015.1117663

Helfer, K. S., & Freyman, R. L. (2008). Aging and speech-on-speech masking. *Ear and Hearing, 29*(1), 87-98. doi:10.1097/AUD.0b013e31815d638b

Henshaw, H., & Ferguson, M. A. (2013). Efficacy of individual computer-based auditory training for people with hearing loss: a systematic review of the evidence. *PLoS One, 8*(5), e62836. doi:10.1371/journal.pone.0062836

Hetu, R., Riverin, L., Lalande, N., Getty, L., & St-Cyr, C. (1988). Qualitative analysis of the handicap associated with occupational hearing loss. *British Journal of Audiology, 22*(4), 251-264. doi:10.3109/03005368809076462

Hickson, L., Worrall, L., & Scarinci, N. (2006). Measuring outcomes of a communication program for older people with hearing impairment using the International Outcome Inventory. *International Journal of Audiology, 45*(4), 238-246. doi:10.1080/14992020500429625

Hornsby, B. W. (2013). The effects of hearing aid use on listening effort and mental fatigue associated with sustained speech processing demands. *Ear and Hearing, 34*(5), 523-534. doi:10.1097/AUD.0b013e31828003d8

Hougaard, S., & Ruf, S. (2011). EuroTrak I: A consumer survey about hearing aids in Germany, France and the UK. *The Hearing Review, 18*(2), 12-28.

Humes, L. E., Dubno, J. R., Gordon-Salant, S., Lister, J. J., Cacace, A. T., Cruickshanks, K. J., . . . Wingfield, A. (2012). Central presbycusis: a review and evaluation of the evidence. *Journal of the American Academy of Audiology, 23*(8), 635-666. doi:10.3766/jaaa.23.8.5

Humes, L. E., Watson, B. U., Christensen, L. A., Cokely, C. G., Halling, D. C., & Lee, L. (1994). Factors associated with individual differences in clinical measures of speech recognition among the elderly. *Journal of Speech and Hearing Research, 37*(2), 465-474. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/8028328

Humes, L. E., Wilson, D. L., Barlow, N. N., & Garner, C. (2002). Changes in hearing-aid benefit following 1 or 2 years of hearing-aid use by older adults. *Journal of Speech, Language and Hearing Research, 45*(4), 772-782. Retrieved from https://www.ncbi.nlm.nih.gov/pubmed/12199406

Jaeger, J. (2018). Digit Symbol Substitution Test: The Case for Sensitivity Over Specificity in Neuropsychological Testing. *Journal of Clinical Psychopharmacology, 38*(5), 513-519. doi:10.1097/JCP.0000000000000941

James, J. S., Kumari, S. R., Sreedharan, R. M., Thomas, B., Radhkrishnan, A., & Kesavadas, C. (2015). Analyzing functional, structural, and anatomical correlation of hemispheric language lateralization in healthy subjects using functional MRI, diffusion tensor imaging, and voxel-based morphometry. *Neurology India, 63*(1), 49-57. doi:10.4103/0028-3886.152634

Kahneman, D. (1973). *Attention and Effort*. NJ: Prentice-Hall, Inc.

Kamil, R. J., & Lin, F. R. (2015). The effects of hearing impairment in older adults on communication partners: a systematic review. *Journal of the American Academy of Audiology, 26*(2), 155-182. doi:10.3766/jaaa.26.2.6

Karawani, H., Jenkins, K. A., & Anderson, S. (2018). Neural and behavioral changes after the use of hearing aids. *Clinical Neurophysiology, 129*(6), 1254-1267. doi:10.1016/j.clinph.2018.03.024

Keidser, G., Rohrseitz, K., Dillon, H., Hamacher, V., Carter, L., Rass, U., & Convery, E. (2006). The effect of multi-channel wide dynamic range compression, noise reduction, and the directional microphone on horizontal localization performance in hearing aid wearers. *International Journal of Audiology, 45*(10), 563-579. doi:10.1080/14992020600920804

Kelly, R. J., & Atcherson, S. R. (2011). Quality of life for individuals with hearing impairment who have not consulted for services and their significant others: same- and different-sex couples. *Journal of Communication Disorders, 44*(3), 336-344. doi:10.1016/j.jcomdis.2011.01.004

Kiessling, J., Pichora-Fuller, M. K., Gatehouse, S., Stephens, D., Arlinger, S., Chisolm, T., . . . von Wedel, H. (2003). Candidature for and delivery of audiological services: special needs of older people. *International Journal of Audiology, 42 Suppl 2*, 2S92-101. Retrieved from https://www.ncbi.nlm.nih.gov/pubmed/12918635

Knopman, D. S., & Petersen, R. C. (2014). Mild cognitive impairment and mild dementia: a clinical perspective. *Mayo Clinic Proceedings, 89*(10), 1452-1459. doi:10.1016/j.mayocp.2014.06.019

Knutson, J. F., Johnson, A., & Murray, K. T. (2006). Social and emotional characteristics of adults seeking a cochlear implant and their spouses. *British Journal of Health Psychology, 11*(Pt 2), 279-292. doi:10.1348/135910705X52273

Kochkin, S. (2002). 10-year customer satifaction trends in the US hearing instrument market. *The Hearing Review, 9*(10), 14-46.

Koelewijn, T., de Kluiver, H., Shinn-Cunningham, B. G., Zekveld, A. A., & Kramer, S. E. (2015). The pupil response reveals increased listening effort when it is difficult to focus attention. *Hearing Research, 323*, 81-90. doi:10.1016/j.heares.2015.02.004

Kramer, S. E., Kapteyn, T. S., & Houtgast, T. (2006). Occupational performance: comparing normally-hearing and hearing-impaired employees using the Amsterdam Checklist for Hearing and Work. *International Journal of Audiology, 45*(9), 503-512. doi:10.1080/14992020600754583

Kricos, P. B. (2000). The influence of nonaudiological variables on audiological rehabilitation outcomes. *Ear and Hearing, 21*(4 Suppl), 7S-14S. doi:10.1097/00003446-200008001-00003

Laperuta, E. B., & Fiorini, A. C. (2012). Satisfaction of elderly individuals with hearing aids in the first six months of use. *Jornal da Sociedade Brasileira de Fonoaudiologia, 24*(4), 316-321. doi:10.1590/s2179-64912012000400005

Laplante-Levesque, A., Hickson, L., & Worrall, L. (2010). Rehabilitation of older adults with hearing impairment: a critical review. *Journal of Aging and Health, 22*(2), 143-153. doi:10.1177/0898264309352731

Larsby, B., Hallgren, M., Lyxell, B., & Arlinger, S. (2005). Cognitive performance and perceived effort in speech processing tasks: effects of different noise backgrounds in normal-hearing and hearing-impaired subjects. *International Journal of Audiology, 44*(3), 131-143. doi:10.1080/14992020500057244

Larson, V. D., Williams, D. W., Henderson, W. G., Luethke, L. E., Beck, L. B., Noffsinger, D., . . . Rappaport, B. Z. (2000). Efficacy of 3 commonly used hearing aid circuits: A crossover trial. NIDCD/VA Hearing Aid Clinical Trial Group. *JAMA, 284*(14), 1806-1813. doi:10.1001/jama.284.14.1806

Laux, L. F., Lane, D.M. (1985). Information processing components of substitution test performance. *Dermatologie internationale, 9*, 111-116.

Lavie, L., Attias, J., & Karni, A. (2013). Semi-structured listening experience (listening training) in hearing aid fitting: influence on dichotic listening. *American Journal of Audiology, 22*(2), 347-350. doi:10.1044/1059-0889(2013/12-0083)

Lee, K. Y. (2013). Pathophysiology of age-related hearing loss (peripheral and central). *Korean Journal of Audiology, 17*(2), 45-49. doi:10.7874/kja.2013.17.2.45

Leising, D., Locke, K. D., Kurzius, E., & Zimmermann, J. (2016). Quantifying the Association of Self-Enhancement Bias With Self-Ratings of Personality and Life Satisfaction. *Assessment, 23*(5), 588-602. doi:10.1177/1073191115590852

Lesica, N. A. (2018). Why Do Hearing Aids Fail to Restore Normal Auditory Perception? *Trends in Neurosciences, 41*(4), 174-185. doi:10.1016/j.tins.2018.01.008

Leventhal, H., Meyer, D., & Nerenz, D. (1980). The common sense model of illness danger. In S. Rachman (Ed.), *Medical psychology* (Vol. 2, pp. 7-30). New York, Pergamon.

Lezak, M. D. (1995). *Neuropsychological Assessment* (3rd ed.). New York.

Lin, F. R., & Albert, M. (2014). Hearing loss and dementia - who is listening? *Aging & Mental Health, 18*(6), 671-673. doi:10.1080/13607863.2014.915924

Lin, F. R., Ferrucci, L., An, Y., Goh, J. O., Doshi, J., Metter, E. J., . . . Resnick, S. M. (2014). Association of hearing impairment with brain volume changes in older adults. *Neuroimage, 90*, 84-92. doi:10.1016/j.neuroimage.2013.12.059

Lin, F. R., Ferrucci, L., Metter, E. J., An, Y., Zonderman, A. B., & Resnick, S. M. (2011). Hearing loss and cognition in the Baltimore Longitudinal Study of Aging. *Neuropsychology, 25*(6), 763-770. doi:10.1037/a0024238

Lin, F. R., Metter, E. J., O'Brien, R. J., Resnick, S. M., Zonderman, A. B., & Ferrucci, L. (2011). Hearing loss and incident dementia. *Archives of Neurology, 68*(2), 214-220. doi:10.1001/archneurol.2010.362

Lormore, K. A., & Stephens, S. D. (1994). Use of the open-ended questionnaire with patients and their significant others. *British Journal of Audiology, 28*(2), 81-89. doi:10.3109/03005369409077918

Lunner, T. (2003). Cognitive function in relation to hearing aid use. *International Journal of Audiology, 42 Suppl 1*, S49-58. Retrieved from https://www.ncbi.nlm.nih.gov/pubmed/12918610

Lunner, T., Rudner, M., & Ronnberg, J. (2009). Cognition and hearing aids. *Scandinavian Journal of Psychology, 50*(5), 395-403. doi:10.1111/j.1467-9450.2009.00742.x

Lunner, T., & Sundewall-Thoren, E. (2007). Interactions between cognition, compression, and listening conditions: effects on speech-in-noise performance in a two-channel hearing aid. *Journal of the American Academy of Audiology, 18*(7), 604-617. doi:10.3766/jaaa.18.7.7

Lupsakko, T. A., Kautiainen, H. J., & Sulkava, R. (2005). The non-use of hearing aids in people aged 75 years and over in the city of Kuopio in Finland. *European Archives of Oto-rhino-laryngology, 262*(3), 165-169. doi:10.1007/s00405-004-0789-x

Magnusson, L., Claesson, A., Persson, M., & Tengstrand, T. (2013). Speech recognition in noise using bilateral open-fit hearing aids: the limited benefit of directional microphones and noise reduction. *International Journal of Audiology, 52*(1), 29-36. doi:10.3109/14992027.2012.707335

Mahoney, C. F., Stephens, S. D., & Cadge, B. A. (1996). Who prompts patients to consult about hearing loss? *British Journal of Audiology, 30*(3), 153-158. doi:10.3109/03005369609079037

McCormack, A., & Fortnum, H. (2013). Why do people fitted with hearing aids not wear them? *International Journal of Audiology, 52*(5), 360-368. doi:10.3109/14992027.2013.769066

McCullagh, J. P. (2009). *An investigation of central auditory system plasticity following amplification* (Doctoral Dissertations). University of Connecticut, Retrieved from https://opencommons.uconn.edu/dissertations/AAI3360701

McGarrigle, R., Munro, K. J., Dawes, P., Stewart, A. J., Moore, D. R., Barry, J. G., & Amitay, S. (2014). Listening effort and fatigue: what exactly are we measuring? A British Society of Audiology Cognition in Hearing Special Interest Group 'white paper'. *International Journal of Audiology, 53*(7), 433-440. doi:10.3109/14992027.2014.890296

Meiberth, D., Scheef, L., Wolfsgruber, S., Boecker, H., Block, W., Traber, F., . . . Jessen, F. (2015). Cortical thinning in individuals with subjective memory impairment. *Journal of Alzheimer's Disease, 45*(1), 139-146. doi:10.3233/JAD-142322

Mener, D. J., Betz, J., Genther, D. J., Chen, D., & Lin, F. R. (2013). Hearing loss and depression in older adults. *Journal of the American Geriatrics Society, 61*(9), 1627-1629. doi:10.1111/jgs.12429

Meyer, C., & Hickson, L. (2012). What factors influence help-seeking for hearing impairment and hearing aid adoption in older adults? *International Journal of Audiology, 51*(2), 66-74. doi:10.3109/14992027.2011.611178

Mitchell, A. J., & Shiri-Feshki, M. (2009). Rate of progression of mild cognitive impairment to dementia—meta-analysis of 41 robust inception cohort studies. *Acta Psychiatrica Scandinavia, 119*(4), 252-265. doi:10.1111/j.1600-0447.2008.01326.x

Montori, V. M., Gafni, A., & Charles, C. (2006). A shared treatment decision-making approach between patients with chronic conditions and their clinicians: the case of diabetes. *Health Expectations, 9*(1), 25-36. doi:10.1111/j.1369-7625.2006.00359.x

Mulrow, C. D., Tuley, M. R., & Aguilar, C. (1992). Sustained benefits of hearing aids. *Journal of Speech and Hearing Research, 35*(6), 1402-1405. doi:10.1044/jshr.3506.1402

Munro, K. J., & Lutman, M. E. (2003). The effect of speech presentation level on measurement of auditory acclimatization to amplified speech. *The Journal of the Acoustical Society of America, 114*(1), 484-495. Retrieved from https://www.ncbi.nlm.nih.gov/pubmed/12880059

Nachtegaal, J., Festen, J. M., & Kramer, S. E. (2011). Hearing Ability and its Relationship with Psychosocial Health, Work-Related Variables, and Health Care Use: The National Longitudinal Study on Hearing. *Audiology Research, 1*(1), e9. doi:10.4081/audiores.2011.e9

Nasreddine, Z. S., Phillips, N. A., Bedirian, V., Charbonneau, S., Whitehead, V., Collin, I., . . . Chertkow, H. (2005). The Montreal Cognitive Assessment, MoCA: a brief screening tool for mild cognitive impairment. *Journal of the American Geriatrics Society, 53*(4), 695-699. doi:10.1111/j.1532-5415.2005.53221.x

Neher, T., Grimm, G., Hohmann, V., & Kollmeier, B. (2014). Do hearing loss and cognitive function modulate benefit from different binaural noise-reduction settings? *Ear and Hearing, 35*(3), e52-62. doi:10.1097/AUD.0000000000000003

Nkyekyer, J., Meyer, D., Pipingas, A., & Reed, N. S. (2019). The cognitive and psychosocial effects of auditory training and hearing aids in adults with hearing loss. *Clinical Interventions in Aging, 14*, 123-135. doi:10.2147/CIA.S183905

Oberg, M., Marcusson, J., Nagga, K., & Wressle, E. (2012). Hearing difficulties, uptake, and outcomes of hearing aids in people 85 years of age. *International Journal of Audiology, 51*(2), 108-115. doi:10.3109/14992027.2011.622301

Ohlenforst, B., Zekveld, A. A., Jansma, E. P., Wang, Y., Naylor, G., Lorens, A., . . . Kramer, S. E. (2017). Effects of Hearing Impairment and Hearing Aid Amplification on Listening Effort: A Systematic Review. *Ear and Hearing, 38*(3), 267-281. doi:10.1097/AUD.0000000000000396

Oliveira, J. R., Lopes, E. S., & Alves, A. F. (2010). Speech perception of hearing impaired people using a hearing aid with noise supression algorithms. *Brazilian Journal of Otorhinolaryngology, 76*(1), 14-17. Retrieved from https://www.ncbi.nlm.nih.gov/pubmed/20339683

Olson, A. D. (2015). Options for Auditory Training for Adults with Hearing Loss. *Seminars in Hearing, 36*(4), 284-295. doi:10.1055/s-0035-1564461

Petersen, E. B., Wostmann, M., Obleser, J., Stenfelt, S., & Lunner, T. (2015). Hearing loss impacts neural alpha oscillations under adverse listening conditions. *Frontiers in Psychology, 6*, 177. doi:10.3389/fpsyg.2015.00177

Pfeiffer, E. (1975). A short portable mental status questionnaire for the assessment of organic brain deficit in elderly patients. *Journal of the American Geriatrics Society, 23*(10), 433-441. doi:10.1111/j.1532-5415.1975.tb00927.x

Philibert, B., Collet, L., Vesson, J. F., & Veuillet, E. (2005). The auditory acclimatization effect in sensorineural hearing-impaired listeners: evidence for functional plasticity. *Hearing Research, 205*(1-2), 131-142. doi:10.1016/j.heares.2005.03.013

Pichora-Fuller, M. K., Kramer, S. E., Eckert, M. A., Edwards, B., Hornsby, B. W., Humes, L. E., . . . Wingfield, A. (2016). Hearing Impairment and Cognitive Energy: The Framework for Understanding Effortful Listening (FUEL). *Ear and Hearing, 37 Suppl 1*, 5S-27S. doi:10.1097/AUD.0000000000000312

Pichora-Fuller, M. K., & Singh, G. (2006). Effects of age on auditory and cognitive processing: implications for hearing aid fitting and audiologic rehabilitation. *Trends in Amplification, 10*(1), 29-59. doi:10.1177/108471380601000103

Picou, E. M., Aspell, E., & Ricketts, T. A. (2014). Potential benefits and limitations of three types of directional processing in hearing aids. *Ear and Hearing, 35*(3), 339-352. doi:10.1097/AUD.0000000000000004

Picou, E. M., Gordon, J., & Ricketts, T. A. (2016). The Effects of Noise and Reverberation on Listening Effort in Adults With Normal Hearing. *Ear and Hearing, 37*(1), 1-13. doi:10.1097/AUD.0000000000000222

Picou, E. M., Ricketts, T. A., & Hornsby, B. W. (2011). Visual cues and listening effort: individual variability. *Journal of Speech, Language and Hearing Research, 54*(5), 1416-1430. doi:10.1044/1092-4388(2011/10-0154)

Pinheiro, M. M., Iorio, M. C., Miranda, E. C., Dias, K. Z., & Pereira, L. D. (2012). The influence of cognitive aspects and auditory processes on the hearing aid acclimatization in the elderly.

Jornal da Sociedade Brasileira de Fonoaudiologica, 24(4), 309-315. doi:10.1590/s2179-64912012000400004

Plomp, R. (1978). Auditory handicap of hearing impairment and the limited benefit of hearing aids. *The Journal of the Acoustical Society of America, 63*(2), 533-549. doi:10.1121/1.381753

Portet, F., Ousset, P. J., Visser, P. J., Frisoni, G. B., Nobili, F., Scheltens, P., . . . MCI Working Group of the European Consortium on Alzheimer's Disease (EADC) (2006). Mild cognitive impairment (MCI) in medical practice: a critical review of the concept and new diagnostic procedure. Report of the MCI Working Group of the European Consortium on Alzheimer's Disease. *Journal of Neurology, Neurosurgery, and Psychiatry, 77*(6), 714-718. doi:10.1136/jnnp.2005.085332

Prete, G., D'Anselmo, A., Brancucci, A., & Tommasi, L. (2018). Evidence of a Right Ear Advantage in the absence of auditory targets. *Scientific Reports, 8*(1), 15569. doi:10.1038/s41598-018-34086-3

Qian, Z. J., Wattamwar, K., Caruana, F. F., Otter, J., Leskowitz, M. J., Siedlecki, B., . . . Lalwani, A. K. (2016). Hearing Aid Use is Associated with Better Mini-Mental State Exam Performance. *The American Journal of Geriatric Psychiatry, 24*(9), 694-702. doi:https://doi.org/10.1016/j.jagp.2016.03.005

Reinhart, P. N., & Souza, P. E. (2016). Intelligibility and Clarity of Reverberant Speech: Effects of Wide Dynamic Range Compression Release Time and Working Memory. *Journal of Speech, Language and Hearing Research, 59*(6), 1543-1554. doi:10.1044/2016_JSLHR-H-15-0371

Ricketts, T., Henry, P., & Gnewikow, D. (2003). Full time directional versus user selectable microphone modes in hearing aids. *Ear and Hearing, 24*(5), 424-439. doi:10.1097/01.AUD.0000094555.89110.0A

Ricketts, T. A. (2001). Directional hearing aids. *Trends in Amplification, 5*(4), 139-176. doi:10.1177/108471380100500401

Ricketts, T. A. (2005). Directional hearing aids: then and now. *Journal of Rehabilitation Research and Development, 42*(4 Suppl 2), 133-144. Retrieved from https://www.ncbi.nlm.nih.gov/pubmed/16470469

Ricketts, T. A., Henry, P. P., & Hornsby, B. W. (2005). Application of frequency importance functions to directivity for prediction of benefit in uniform fields. *Ear and Hearing, 26*(5), 473-486. doi:10.1097/01.aud.0000179691.21547.01

Ricketts, T. A., & Hornsby, B. W. (2005). Sound quality measures for speech in noise through a commercial hearing aid implementing digital noise reduction. *Journal of the American Academy of Audiology, 16*(5), 270-277. doi:10.3766/jaaa.16.5.2

Ronnberg, J., Lunner, T., Zekveld, A., Sorqvist, P., Danielsson, H., Lyxell, B., . . . Rudner, M. (2013). The Ease of Language Understanding (ELU) model: theoretical, empirical, and clinical advances. *Frontiers in Systems Neuroscience, 7*, 31. doi:10.3389/fnsys.2013.00031

Rosengard, P. S., Payton, K. L., & Braida, L. D. (2005). Effect of slow-acting wide dynamic range compression on measures of intelligibility and ratings of speech quality in simulated-loss listeners. *Journal of Speech, Language and Hearing Research, 48*(3), 702-714. doi:10.1044/1092-4388(2005/048)

Ruan, Q., Ma, C., Zhang, R., & Yu, Z. (2014). Current status of auditory aging and anti-aging research. *Geriatrics and Gerontology International, 14*(1), 40-53. doi:10.1111/ggi.12124

Rudner, M., Foo, C., Ronnberg, J., & Lunner, T. (2009). Cognition and aided speech recognition in noise: specific role for cognitive factors following nine-week experience with adjusted compression settings in hearing aids. *Scandinavian Journal of Psychology, 50*(5), 405-418. doi:10.1111/j.1467-9450.2009.00745.x

Salthouse TA. Speed mediation of adult age differences in cognition. Developmental Psychology. 1993;29:722–738.

Sarampalis, A., Kalluri, S., Edwards, B., & Hafter, E. (2009). Objective measures of listening effort: effects of background noise and noise reduction. *Journal of Speech, Language and Hearing Research, 52*(5), 1230-1240. doi:10.1044/1092-4388(2009/08-0111)

Saunders, G. H., & Cienkowski, K. M. (1997). Acclimatization to hearing aids. *Ear and Hearing, 18*(2), 129-139. Retrieved from https://www.ncbi.nlm.nih.gov/pubmed/9099562

Savundranayagam, M. Y., Hummert, M. L., & Montgomery, R. J. (2005). Investigating the effects of communication problems on caregiver burden. *The Journals of Gerontology. Series B, Psychological Sciences and Social Sciences, 60*(1), S48-55. doi:10.1093/geronb/60.1.s48

Scarinci, N., Worrall, L., & Hickson, L. (2008). The effect of hearing impairment in older people on the spouse. *International Journal of Audiology, 47*(3), 141-151. doi:10.1080/14992020701689696

Scarinci, N., Worrall, L., & Hickson, L. (2012). Factors associated with third-party disability in spouses of older people with hearing impairment. *Ear and Hearing, 33*(6), 698-708. doi:10.1097/AUD.0b013e31825aab39

Schneider, B. A., Daneman, M., & Pichora-Fuller, M. K. (2002). Listening in aging adults: from discourse comprehension to psychoacoustics. *Canadian Journal of Experimental Psychology, 56*(3), 139-152. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/12271745

Seniors Research Group. (1999). *The consequences of untreated hearing loss in older persons*.

Silva, D. P., Silva, V. B., & Aurelio, F. S. (2013). Auditory satisfaction of patients fitted with hearing aids in the Brazilian Public Health Service and benefits offered by the hearing aids. *Brazilian Journal of Otorhinolaryngology, 79*(5), 538-545. doi:10.5935/1808-8694.20130098

Simpson, A. N., Matthews, L. J., Cassarly, C., & Dubno, J. R. (2019). Time From Hearing Aid Candidacy to Hearing Aid Adoption: A Longitudinal Cohort Study. *Ear and Hearing, 40*(3), 468-476. doi:10.1097/AUD.0000000000000641

Smith, S. L., Pichora-Fuller, M. K., & Alexander, G. (2016). Development of the Word Auditory Recognition and Recall Measure: A Working Memory Test for Use in Rehabilitative Audiology. Ear and hearing, 37(6), e360–e376. https://doi.org/10.1097/AUD.0000000000000329

Solheim, J., & Hickson, L. (2017). Hearing aid use in the elderly as measured by datalogging and self-report. *International Journal of Audiology, 56*(7), 472-479. doi:10.1080/14992027.2017.1303201

Song, J. H., Nicol, T., & Kraus, N. (2011). Test-retest reliability of the speech-evoked auditory brainstem response. *Clinical Neurophysiology, 122*(2), 346-355. doi:10.1016/j.clinph.2010.07.009

Souza, P., Arehart, K., & Neher, T. (2015). Working Memory and Hearing Aid Processing: Literature Findings, Future Directions, and Clinical Applications. *Frontiers in Psychology, 6*, 1894. doi:10.3389/fpsyg.2015.01894

Souza, P. E. (2002). Effects of compression on speech acoustics, intelligibility, and sound quality. *Trends in Amplification, 6*(4), 131-165. doi:10.1177/108471380200600402

Spulber, G., Niskanen, E., Macdonald, S., Kivipelto, M., Padilla, D. F., Julkunen, V., . . . Soininen, H. (2012). Evolution of global and local grey matter atrophy on serial MRI scans during the progression from MCI to AD. *Current Alzheimer's Research, 9*(4), 516-524. doi:10.2174/156720512800492486

Stark, P., & Hickson, L. (2004). Outcomes of hearing aid fitting for older people with hearing impairment and their significant others. *International Journal of Audiology, 43*(7), 390-398. doi:10.1080/14992020400050050

Stecker, G. C., Bowman, G. A., Yund, E. W., Herron, T. J., Roup, C. M., & Woods, D. L. (2006). Perceptual training improves syllable identification in new and experienced hearing aid users. *Journal of Rehabilitation Research and Development, 43*(4), 537-552. doi:10.1682/jrrd.2005.11.0171

Stephens, D., France, L., & Lormore, K. (1995). Effects of hearing impairment on the patient's family and friends. *Acta Oto-laryngolica, 115*(2), 165-167. doi:10.3109/00016489509139283

Stephens, S., & Meredith, R. (1991). Qualitative reports of hearing aid benefit. *Clinical Rehabilitation, 5*(3), 225-229.

Stone, M. A., & Moore, B. C. (2008). Effects of spectro-temporal modulation changes produced by multi-channel compression on intelligibility in a competing-speech task. *The Journal of the Acoustical Society of America, 123*(2), 1063-1076. doi:10.1121/1.2821969

Stone, M. A., Moore, B. C., Meisenbacher, K., & Derleth, R. P. (2008). Tolerable hearing aid delays. V. Estimation of limits for open canal fittings. *Ear and Hearing, 29*(4), 601-617. doi:10.1097/AUD.0b013e3181734ef2

Strawbridge, W. J., Wallhagen, M. I., Shema, S. J., & Kaplan, G. A. (2000). Negative consequences of hearing impairment in old age: a longitudinal analysis. *Gerontologist, 40*(3), 320-326. doi:10.1093/geront/40.3.320

Styles, E. A. (2006). *The psychology of attention: Second Edition*. New York: Psychology Press.

Tambs, K. (2004). Moderate effects of hearing loss on mental health and subjective well-being: results from the Nord-Trondelag Hearing Loss Study. *Psychosomatic Medicine, 66*(5), 776-782. doi:10.1097/01.psy.0000133328.03596.fb

Taylor, & Mueller, G. (2016). *Fitting and dispensing hearing aids* (2nd ed.): Plural Publishing.

Taylor, K. S. (1993). Self-perceived and audiometric evaluations of hearing aid benefit in the elderly. *Ear and Hearing, 14*(6), 390-394. Retrieved from https://www.ncbi.nlm.nih.gov/pubmed/8307242

Tervaniemi, M., & Hugdahl, K. (2003). Lateralization of auditory-cortex functions. *Brain Research. Brain Research Reviews, 43*(3), 231-246. doi:10.1016/j.brainresrev.2003.08.004

Tirre, W., & Pena, C. (1992). Investigation of functional working memory in the Reading span test. *Journal of Educational Psychology, 84*(4), 462-472.

Tun, P. A., McCoy, S., & Wingfield, A. (2009). Aging, hearing acuity, and the attentional costs of effortful listening. *Psychology and Aging, 24*(3), 761-766. doi:10.1037/a0014802

Turner, C. W., & Bentler, R. A. (1998). Does hearing aid benefit increase over time? *The Journal of the Acoustical Society of America, 104*(6), 3673-3674. Retrieved from https://www.ncbi.nlm.nih.gov/pubmed/9857524

Valente, M., Fabry, D. A., & Potts, L. G. (1995). Recognition of speech in noise with hearing aids using dual microphones. *Journal of the American Academy of Audiology, 6*(6), 440-449. Retrieved from https://www.ncbi.nlm.nih.gov/pubmed/8580504

Vaughan, N., Storzbach, D., & Furukawa, I. (2006). Sequencing versus nonsequencing working memory in understanding of rapid speech by older listeners. *Journal of the American Academy of Audiology, 17*(7), 506-518. Retrieved from https://www.ncbi.nlm.nih.gov/pubmed/16927515

Vestergaard, M. D. (2006). Self-report outcome in new hearing-aid users: Longitudinal trends and relationships between subjective measures of benefit and satisfaction. *International Journal of Audiology, 45*(7), 382-392. doi:10.1080/14992020600690977

Walden, B. E., Surr, R. K., Cord, M. T., Edwards, B., & Olson, L. (2000). Comparison of benefits provided by different hearing aid technologies. *Journal of the American Academy of Audiology, 11*(10), 540-560. Retrieved from https://www.ncbi.nlm.nih.gov/pubmed/11198072

Walden, B. E., Surr, R. K., Grant, K. W., Van Summers, W., Cord, M. T., & Dyrlund, O. (2005). Effect of Signal-to-Noise Ratio on Directional Microphone Benefit and Preference. *Journal of the American Academy of Audiology, 16*(9), 662-676. doi:10.3766/jaaa.16.9.4

Wallhagen, M. I. (2010). The stigma of hearing loss. *Gerontologist, 50*(1), 66-75. doi:10.1093/geront/gnp107

Wallhagen, M. I., Strawbridge, W. J., & Kaplan, G. A. (1996). 6-year impact of hearing impairment on psychosocial and physiologic functioning. *The Nurse Practitioner, 21*(9), 11-14. Retrieved from https://www.ncbi.nlm.nih.gov/pubmed/8884790

Wallhagen, M. I., Strawbridge, W. J., Shema, S. J., & Kaplan, G. A. (2004). Impact of self-assessed hearing loss on a spouse: a longitudinal analysis of couples. *The Journals of Gerontology. Series B, Psychological Sciences and Social Sciences, 59*(3), S190-196. doi:10.1093/geronb/59.3.s190

Wechsler, D. (1997). WAIS-II administration and scoring manual. *The psychological Corporation*.

Weinstein, B. E., Spitzer, J. B., & Ventry, I. M. (1986). Test-retest reliability of the Hearing Handicap Inventory for the Elderly. *Ear and Hearing, 7*(5), 295-299. doi:10.1097/00003446-198610000-00002

Weschler, D. (1939). *The measurement of adult intelligence*. Baltimore.

Wickens, C. D. (1992). *Engineering psychology and human performance*. New York: HarperCollins Publisher Inc.

Wilson, R. H. (1993). Development and use of auditory compact discs in auditory evaluation. *Journal of Rehabilitation Research and Development, 30*(3), 342-351. Retrieved from https://www.ncbi.nlm.nih.gov/pubmed/8126659

Wingfield, A., Lindfield, K. C., & Goodglass, H. (2000). Effects of age and hearing sensitivity on the use of prosodic information in spoken word recognition. *Journal of Speech, Language and Hearing Research, 43*(4), 915-925. doi:10.1044/jslhr.4304.915

Wingfield, A., & Tun, P. (2001). Spoken language comprehension in older adults: interactions between sensory and cognitive change in normal aging. *Seminars in Hearing, 22*(3), 287-302.

Winkler, A., Latzel, M., & Holube, I. (2016). Open Versus Closed Hearing-Aid Fittings: A Literature Review of Both Fitting Approaches. *Trends in Hearing, 20*. doi:10.1177/2331216516631741

World Health Organization. (2018). Deafness and hearing loss. Retrieved from https://www.who.int/news-room/fact-sheets/detail/deafness-and-hearing-loss

Wright, D., & Gagné, J.-P. (2020). Acclimatization to hearings aids by older adults. *Ear and Hearing, July 2020*. doi:10.1097/AUD.0000000000000913

Wright, D., Hotton, M., & Gagné, J.-P. (2020). Systematic review on acclimatization to hearing aids. *Manuscript submitted for publication*.

Wu, Y. H., Stangl, E., Bentler, R. A., & Stanziola, R. W. (2013). The effect of hearing aid technologies on listening in an automobile. *Journal of the American Academy of Audiology, 24*(6), 474-485. doi:10.3766/jaaa.24.6.4

Wu, Y. H., Stangl, E., Zhang, X., Perkins, J., & Eilers, E. (2016). Psychometric Functions of Dual-Task Paradigms for Measuring Listening Effort. *Ear and Hearing, 37*(6), 660-670. doi:10.1097/AUD.0000000000000335

Xia, J., Nooraei, N., Kalluri, S., & Edwards, B. (2015). Spatial release of cognitive load measured in a dual-task paradigm in normal-hearing and hearing-impaired listeners. *The Journal of the Acoustical Society of America, 137*(4), 1888-1898. doi:10.1121/1.4916599

Yesavage, J. A., & Tinklenberg, J. R. (1983). Tests d'attention, de mémoire et de performance motrice sur ordinateur appliqués à la recherche en gériatrie [Computerized tests of attention, memory and motor performance applied to geriatric research]. *Presse Med, 12*(48), 3170-3172. Retrieved from https://www.ncbi.nlm.nih.gov/pubmed/6228935

Yund, E. W., & Buckles, K. M. (1995). Enhanced speech perception at low signal-to-noise ratios with multichannel compression hearing aids. *The Journal of the Acoustical Society of America, 97*(2), 1224-1240. doi:10.1121/1.412232

Zekveld, A. A., & Kramer, S. E. (2014). Cognitive processing load across a wide range of listening conditions: insights from pupillometry. *Psychophysiology, 51*(3), 277-284. doi:10.1111/psyp.12151

Zekveld, A. A., Kramer, S. E., & Festen, J. M. (2010). Pupil response as an indication of effortful listening: the influence of sentence intelligibility. *Ear and Hearing, 31*(4), 480-490. doi:10.1097/AUD.0b013e3181d4f251

Zekveld, A. A., Kramer, S. E., & Festen, J. M. (2011). Cognitive load during speech perception in noise: the influence of age, hearing loss, and cognition on the pupil response. *Ear and Hearing, 32*(4), 498-510. doi:10.1097/AUD.0b013e31820512bb