Aus der Klinik für Hals-, Nasen- und Ohrenheilkunde
im Unfallkrankenhaus Berlin – akademisches Lehrkrankenhaus der
Charité – Universitätsmedizin Berlin

DISSERTATION

Zentralnervöse Integration auditiver und vestibulärer Informationen

Central nervous integration of auditory and vestibular information

zur Erlangung des akademischen Grades
Doctor of Philosophy (PhD)

vorgelegt der Medizinischen Fakultät
Charité – Universitätsmedizin Berlin

von

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Datum der Promotion: 30.11.2023

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List of abbreviations

cN	**c**ontinuous **N**oise
EP	**E**ar **P**rotectors
iN	**i**nterrupted **N**oise
LR	**L**ong **R**everberation time
R	**R**eference
SR	**S**hort **R**everberation time

Zusammenfassung

Einführung

Eine Beeinträchtigung unseres Innenohrsystems kann zu eingeschränkter Lebensqualität führen. Neben dem vestibulären, propriozeptiven und visuellen System könnte der auditive Input die posturale Stabilität beeinflussen. Das Ziel dieser Studie ist es, den auditiven Einfluss auf das Gleichgewicht unter klar definierten akustischen Bedingungen für Bewegungen im Alltag bei jungen und gesunden Menschen zu untersuchen.

Methoden

Die Studienteilnehmer führten Steh- und Gehübungen in einem halligen und in einem reflexionsarmen Raum (nur Stehübungen) durch. Zu den akustischen Konditionen gehörten Ruhe (als Referenzkondition), kontinuierliches/unterbrochenes Rauschen, das von einem Lautsprecher von vorne dargeboten wurde und das Tragen von Gehörschutz (nur Stehübungen). Voruntersuchungen zeigten bei keinem der dreißig Teilnehmer eine Gleichgewichts- oder Hörstörung. Die Winkelgeschwindigkeit des Körpers wurde mit dem VertiGuard® System gemessen, einem Gerät, das nahe am Körperschwerpunkt getragen wurde.

Ergebnisse

Bei 10 von 60 Konditionen der Stehübungen und 3 von 16 Konditionen der Gehübungen veränderte sich die posturale Kontrolle signifikant durch Veränderung der akustischen Kondition. Die Körperschwankungsgeschwindigkeit nahm beim Tragen des Gehörschutzes in beiden Räumen zu. Unterbrochenes Rauschen verringerte die Schwankungsgeschwindigkeit, während kontinuierliches Rauschen die Schwankungsgeschwindigkeit beim Stehen im halligen Raum erhöhte. Die posturale Stabilität änderte sich nicht bei Darbietung des Rauschens im reflexionsarmen Raum. Beim Gehen beeinflusste das Rauschen unabhängig vom Rauschstimulus die posturale Kontrolle positiv. Es gab keine Verbesserung der posturalen Stabilität bei der schwierigsten Steh- und Gehübung (Tandem Romberg Test und Gehen mit gleichzeitigem Drehen des Kopfes).

Schlussfolgerungen

Die Ergebnisse zeigen einen Einfluss der Raumakustik auf die Körperhaltung. Hierbei ist die Einflussnahme abhängig von der Art des akustischen Stimulus und ggf. der kognitiven Anforderung (Komplexität der Aufgabe). Eine wichtige Rolle spielt dabei vermutlich die Lokalisationsfähigkeit und die akustische Raumwahrnehmung. In der klinischen Praxis sollten Gleichgewichtsmessungen in einem normalen Untersuchungsraum durchgeführt und die akustischen Bedingungen während der gesamten Untersuchung konstant gehalten werden. Der Einfluss der akustischen Wahrnehmung auf die Körperhaltung scheint, im Vergleich zu anderen Systemen, die die Körperhaltung beeinflussen, beim gesunden Menschen nur gering zu sein. Im Gegensatz dazu könnten Patienten mit Hör- und Gleichgewichtsstörungen mehr von auditiven Informationen profitieren. Zukünftige Studien sollten sich auf diese Patientengruppen konzentrieren, um neue Behandlungsmethoden zur Verbesserung der Lebensqualität zu entwickeln.

Abstract

Introduction

An impairment of our inner ear system can lead to reduced life quality. Besides the vestibular, proprioceptive and visual system, the auditory input might affect postural stability. This study aimed to investigate the auditory impact on balance in clearly defined acoustic conditions for everyday movements in young and healthy participants.

Methods

Participants performed stance and gait tasks in a reverberant and anechoic room (stance tasks only). Acoustic conditions included quiet (as reference condition), continuous/interrupted noise presented from a speaker from the front and wearing ear protectors (stance tasks only). Preliminary examinations showed no vestibular or hearing disorders in any of the thirty participants. Angular velocity of the body was measured with the VertiGuard® system, a device worn close to the body's center of gravity.

Results

In 10 out of 60 standing conditions and 3 out of 16 walking conditions postural control changed significantly by changing the acoustic condition. Body sway velocity increased when participants wore ear protectors in both rooms. Interrupted noise decreased sway velocity, whereas continuous noise increased sway velocity during standing in the reverberant room. Postural stability did not change in noise conditions in the anechoic room. During walking, noise positively influenced postural control, independent of the noise stimulus. There was no improvement in postural stability for the most difficult stance and gait task (Tandem Romberg test and walking with turning the head).

Conclusion

Results show an influence of the room acoustic on posture. Here, the influence depends on the kind of stimulus signal and potentially the cognitive demand (complexity of the task). An important role seems to play the localization ability and the acoustic spatial perception. In clinical practice, balance recordings should be performed in a normal examination room and the acoustic conditions should be kept constant during the whole testing. The influence of the acoustic perception on posture seems to be only little compared to other postural influencing systems in healthy humans. In contrast, hearing and vestibular impaired patients might benefit more from auditory information. Future studies should focus on these patient groups to develop new treatment methods to improve quality of life.

1. Introduction

Our hearing and vestibular system is indispensable for a good quality of life. Impairments of such a sensorineural system can already lead to severe limitations in daily life. This includes health, psychological and social problems, such as stress, tiredness, headaches, high blood pressure, sleep disorder, depression, injuries from falls, lack of concentration, anxiety, uncertainty, lower resilience, communication deficits, vertigo, nausea and therefore, social isolation, difficulties in relationships within family and among friends, underemployment or unemployment (Bronstein et al., 2010; Dawes et al., 2015; Mendel et al., 1999; Monzani et al., 2001; Neuhauser et al., 2008; Olusanya et al., 2019; Tinetti and Williams, 1997). Treatment of hearing loss and vertigo is therefore crucial to retrieve partly or completely the quality of life.

The World Health Organization estimates the number of people requiring treatment for their hearing impairment at over 5 %. Vestibular vertigo shows a yearly prevalence of at least 4.9 % (Neuhauser et al., 2008). While hearing loss can often be successfully treated with hearing aids or implants, vestibular vertigo is often treated with medication, vestibular rehabilitation exercises or other specific disorder treatments (Swartz and Longwell, 2005). Modern diagnostic methods such as video head impulse test or vestibular evoked myogenic potentials allows a more precise diagnosis and therefore a more specific treatment (Walther, 2017).

1.1 Relationship between the auditory and vestibular system

Hearing impairment and vestibular vertigo often go hand in hand (Newman-Toker et al., 2016). Disorders or injuries of the inner ear, vestibulocochlear nerve or central nervous system can affect the hearing or vestibular system or both. Viral or bacterial infections might result in vertigo and hearing loss (e. g. mumps, cytomegalovirus infection, human immunodeficiency virus infection, meningitis, middle ear infections) (Bertholon and Karkas, 2016; Cohen et al., 2014; El-Badry et al., 2015; Saha, 2021; van der Westhuizen et al., 2013). These infections can cause labyrinthitis, vestibular neuritis or inflammations of other inner ear structures (e. g. cochlea, spiral ganglion cells). Audio-vestibular impairments can also be caused by circulatory disturbances, e. g. due to stroke, transient ischemic attack or cardiovascular disorders (Belmont et al., 2011; Esparza et al., 2007; Saha, 2021). Other candidates of the comorbidities, vertigo and hearing loss, are changes in pressure and of composition of the lymphatic fluid in the inner ear. For example, Ménière's disease or so called idiopathic endolymphatic hydrops causes higher amount of lymphatic fluid in the inner ear that leads to overpressure. This results in a simultaneous overload of vestibulocochlear pressure sensors (hair cells). Further damage to the inner ear structures could be caused by biochemical changes in the lymphatic fluid that result in changes of the endocochlear potential. Certain drugs (like antibiotics) are known to trigger ototoxic processes (Altissimi et al., 2020). Inner and outer ear structures, the central nervous system and its connections can be injured by head trauma, whiplash and tumors that induce temporary or permanent audio-vestibular impairments (e. g. acoustic neuroma) (Fitzgerald, 1996; Saha, 2021). Surgeries on or close to the inner ear can accidentally cause injuries on delicate inner ear structures. For example, a cochlear implant surgery can also lead to temporary or permanent postoperative vertigo (Hänsel et al., 2018). Sensitive labyrinthine structures, such as sacculus and horizontal semicircular canal, could be injured by a traumatic surgery (e. g. direct trauma by electrode insertion, high pressure in the membranous labyrinth during electrode insertion, vibratory trauma by drilling) (Basta et al., 2008; Enticott et al., 2006; Klenzner et al., 2004; Krause et al., 2010; Todt et al., 2008). Postoperative benign positional vertigo, vertigo caused by endolymphatic hydrops or electrical co-stimulation of the vestibular receptors by the cochlear implant have also been described in the literature (Coordes et al., 2012; Kubo et al., 2001; Limb et al., 2005).

Impairments of both, hearing and vestibular system, as comorbidities of the described disorders or injuries can also be due to anatomical and neurophysiological connections between the hearing and vestibular system. The inner ear is of ectodermal origin and consists of the hearing and vestibular organ. All sensory cells of the inner ear bathe in the same lymphatic fluid (Deviterne et al., 2005). The membranous labyrinth of the inner ear is shown schematically in figure 1. Studies investigated neurophysiological connections between both systems (Barker et al., 2012; Bukowska, 2002; Burian and Gstoettner, 1988). First or second order vestibular nerve fibers have been found routed to the dorsal cochlear nucleus in guinea pigs or rabbits by Burian and Gstoettner (1988) and Bukowska (2002). Barker et al. (2012) observed a connection between the lateral vestibular nucleus and the dorsal cochlear nucleus through changes in the expression of certain vesicular glutamate transporters after sound exposure. For the lateral vestibular nucleus input nerve fibers converge mainly from the cerebellum, whereas nerve fibers from the lateral vestibular nucleus descend as lateral vestibulospinal tract to the spinal cord. A stimulation of the motor neurons in the spinal cord can lead to an increased postural stability. Moreover, a connection between the cerebellum and the auditory system is also demonstrated (Baumann and Mattingley, 2010; Grasby et al., 1993; Huang et al., 1982; Petacchi et al., 2005; Snider and Stowell, 1944; Wang et al., 1991; Wolfe, 1972).

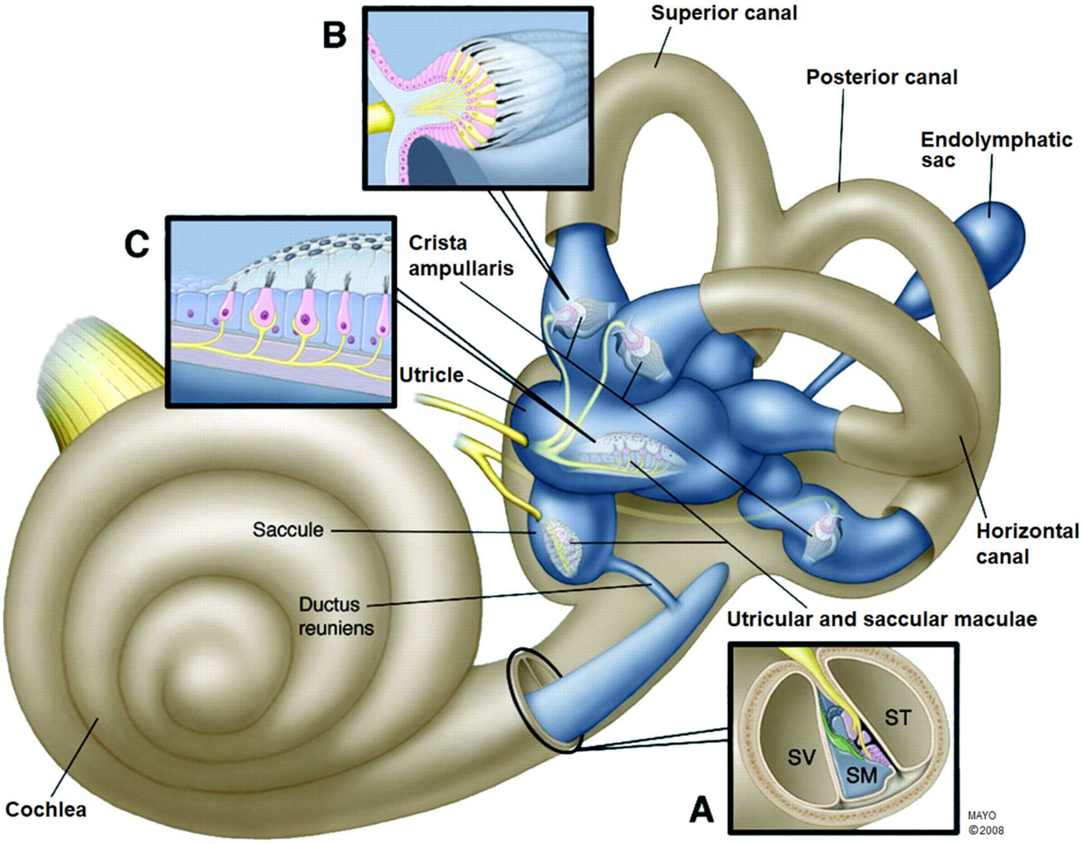


Figure 1: Membranous labyrinth of the inner ear. Magnified cross-section of the cochlea (A), magnified exposed view of the crista ampullaris of the superior semicircular duct (B) and of the utricular macula (C). SV = scala vestibuli, SM = scala media, ST = scala tympani (adapted from fig. 1, Lane et al., 2008)

Another possible explanation for poor balance in hearing impaired patients might be the impaired localization/orientation ability due to reduced access to spatial cues. This could possibly be improved by the use of hearing aid devices (or hearing implants). Hearing impaired patients also have to focus more attention on hearing/listening which costs cognitive resources in the sense of hearing effort (Krüger et al., 2017; Pichora-Fuller et al., 2016). This could lead to reduced attention on their balance which might be needed to maintain balance.

1.2 Effects of auditory input on posture

Positive effects of auditory input on postural control could already be shown in previous studies (Easton et al., 1998; Gandemer et al., 2014; Kanegaonkar et al., 2012; Karim et al., 2018; Munnings et al., 2015; Ross et al., 2016; Seiwerth et al., 2018; Shayman et al., 2017; Stevens et al., 2016; Vitkovic et al., 2016; Zhong and Yost, 2013). Participants improved their postural stability when sound was presented compared to silence during static tasks (Easton et al., 1998; Gandemer et al., 2014; Ross et al., 2016; Stevens et al., 2016; Vitkovic et al., 2016; Zhong and Yost, 2013) and dynamic tasks, such as the Fukuda stepping test (Karim et al., 2018; Munnings et al., 2015; Seiwerth et al., 2018; Zhong and Yost, 2013). Static and dynamic tasks are relevant for everyday movement, but dynamic tasks reflect more the postural response of everyday movement challenges compared to static tasks and have a higher impact on e. g. falls. Furthermore, balance might be more influenced by the auditory system in more complex tasks. Few studies observed a better postural control in hearing impaired patients with their hearing devices turned on versus off for stance and gait tasks (Ibrahim et al., 2019; Negahban et al., 2017; Rumalla et al., 2015; Shayman et al., 2017; Vitkovic et al., 2016; Weaver et al., 2017). This benefit was individual across patients. A similarly positive auditory influence could be seen in vestibular impaired patients (Maheu et al., 2019; Stevens et al., 2016; Vitkovic et al., 2016). Some of these patients were additionally hearing-impaired. The auditory system could possibly have a larger impact on postural stability if one or more of the primary influencing sensory-neural systems is impaired or blocked.

In all these studies the conditions of the participant groups (e. g. normal versus hearing impaired, healthy versus balance impaired, young versus elder, sighted versus blind), the measurement method of body sway (e. g. force platform, video system, inertial or pressure sensors) and the acoustical conditions (e. g. fixed versus moving sound, headphones versus loudspeaker(s), speech signal versus noise) varied widely. However, across all studies, there is only little information about important measurement conditions (e. g. room properties, such as reverberation time and background noise), given. These spatial cues, the acoustic input and the direction(s) the sound is coming from have an impact on the localization ability (Giguère and Abel, 1993; Ihlefeld and Shinn-Cunningham, 2011; Rakerd and Hartmann, 2010; Ribeiro et al., 2010). Postural stability might be positively influenced by a good ability to localize sound (Karim et al., 2018; Seiwerth et al., 2018; Zhong and Yost, 2013).

1.3 Objectives

To characterize the auditory influence on posture in more detail, posture influencing factors were precisely controlled and kept as constant as possible in this study. The participant group underwent comprehensively preliminary investigation that included the investigation of the vision, hearing and balance ability. Furthermore, room acoustic properties such as reverberation time and background noise, and the presented stimulus were precisely determined. A sound level and video recording system was used for subsequent control and analysis. Additionally, the lighting conditions in the rooms were kept constant in all testing.

The present dissertation aimed to precisely characterize the interaction between auditory input and postural stability during everyday movements. This included the investigation of different acoustic conditions during a battery of stance and gait tasks in a homogenous group of young, healthy and normal hearing participants.

The objectives of this dissertation were:

1. To determine the impact of different auditory inputs and room properties on postural stability in stance tasks.

2. To determine the impact of different auditory information on postural control in gait tasks.

The results could help to clarify which auditory cues influence the postural control in daily life to what extent and how could this knowledge contribute to an increased postural stability.

2. Methodology

2.1 Participants

Thirty young and healthy participants with normal hearing and normal vestibular function participated (18 females and 12 males, mean age = 25 years, range = 16-38 years). The hearing status was tested with pure tone audiometry at 0.25, 0.5, 1, 2, 4, 6 and 8 kHz (ISO 7029:2000, 0.1 percentile). All participants showed normal or corrected visual acuity of at least 0.7 logMAR (decimal, tested with Landolt rings). Sacculus and utriculus function were investigated by cervical vestibular evoked myogenic potentials with an ECLIPSE measurement system (Interacoustics, Denmark) and by subjective haptic vertical testing performed with a screening tablet (Zeisberg GmbH, Reutlingen, Germany). The normal function of all semicircular canals was confirmed by the video head impulse test system Eyeseecam® (Otometrics, Denmark). Participants performed the Standard Balance Deficit Test with the VertiGuard® system (Zeisberg GmbH, Reutlingen, Germany) to determine postural stability. Only participants with a normal age-related postural stability (composite score below 50) were included. Subjective vertigo could be excluded by a Dizziness Handicap Inventory summation score below 10. In addition, none of the participants had a history of vertigo or balance problems (anamnesis). Participants with acute or chronic diseases (e. g. respiratory/digestive system/cardiovascular disorders), neurological diseases (e. g. depressions, anxiety, addiction), any neuro-orthopedic diseases (e. g. arthroses of the hip/knee) and any medication intake that profoundly affects the balance system were excluded (e. g. psychotropic drugs). All participants had the same instruction to the tasks to avoid postural variability due to different attentional foci (Bonnet, 2016).

2.2 Room properties

Postural stability was determined in a hallway with a long reverberation time (T30 (125–8000 Hz) = 2.46-1.05 s) (**room LR**) and in an anechoic room with a short reverberation time (T30 (125-8000 Hz) = 0.32-0.16 s) (**room SR**). The reverberation time was similar at several spatial positions. In both rooms, only artificial light was used in order to ensure similar lighting conditions for all participants. A calibrated sound level recording system (measurement microphone Behringer ECM8000, sound calibrator Brüel & Kjær Typ 4230 94 dB 1000 Hz, laptop with preamplifier, recording software audacity version 2.1 and

Spaichinger Schallpegelmesser version 3.1) monitored the ambient noise level (< 40 dB SPL) during the task performances in both rooms. This system was also used to calibrate the stimulus level.

2.3 Procedure and setup

All participants performed five standing and four walking tasks. The test battery included:

- standing with eyes open/closed,
- standing on a foam support with eyes open/closed,
- Tandem Romberg test with eyes closed (heel-to-toe position and arms crossed above shoulders),
- walking with eyes open,
- walking with eyes open and turning head to the right and to the left in rhythm,
- tandem steps with eyes open
- and walking with eyes open over barriers (1 m distance between barriers).

In order to avoid the influence of personal shoes and noise produced by individual clothes of the participants, all participants wore during the task performances similar disposable socks and similar soft pants. The momentary angular velocity ω [°/s] was measured with the VertiGuard system. This device consisted of two gyrometers placed perpendicular to each other to record the momentary angular velocity in two directions, anterior-posterior and medial-lateral (sampling frequency = 80 Hz). The VertiGuard device was placed with a belt on the hip, close to the body's center of gravity. A lower body sway velocity means a more stable posture. All standing tasks were performed in both rooms and walking tasks only in the hallway. Postural stability was determined:

- in quiet as reference condition (**R**),
- with a loudspeaker presenting continuous white noise (**cN**)
- or interrupted white noise from the front (**iN**)
- and participants wore earplugs (Howard Leight Max) and additionally circumaural ear protectors (Moldex M1) (**EP**) (only standing tasks).

The loudspeaker (JBL Control One, frequency range 50-20000 Hz ± 3 dB) stood 1 m (room SR) or 2 m (room LR) in front of the participant at a fixed position for the standing tasks. For the walking tasks the loudspeaker was placed 2 m in front of the participant's end position. Both stimuli, continuous and interrupted noise, consisted of white broadband noise. For the stimulus with interrupted noise, noise and silence alternated every 0.5 s. Noise level was 60 dB SPL at participant's position for standing task performances or at the participant's end position of the walking distance.

The recording time for the standing tasks was 20 s whereby the first and the last second were not analyzed in order to avoid possible artifacts of body sway velocity caused by switching the acoustic stimulus on and off. A total of 18 s were evaluated. Participants walked 12 m (or 6 m for tandem steps) for each walking task. The walking distance included two sections (3 m or 1.5 m for tandem steps) for analyzing the body sway velocity and one section (4 m or 1.5 m for tandem steps) in between to change the acoustic condition. The first and the last two steps were not analyzed as starting and stopping could cause artifacts. In the first analyzed section, no sound was played (reference condition) and in the second analyzed section continuous or interrupted noise was presented. Participants walked in their everyday life walking speed. If the recorded time of both analyzed sections differed more than 10 %, participants were asked to repeat the task. All measurements were recorded with a sound and video system in order to match the measured angular velocity values with the real-time movements and to control that all tasks were performed correctly and that there was no unwanted background noise.

2.4 Statistical analysis

For the data analyses MATLAB R2014b and IBM SPSS version 23 were used. Significant differences between the reference condition R and condition cN, iN or EP were determined for each standing and walking task by applying a t-test for dependent samples or Wilcoxon test (depending on the data distribution, tested with Kolmogorov-Smirnov test). A t-test for independent samples or Mann-Whitney test was performed to determine gender-related differences. All statistical tests were analyzed with a significance level of $p < 0.05$. The reference condition was compared more than once for the standing tasks. Therefore, the p value was corrected using the Bonferroni method.

3. Results

The measured angular velocities ω in °/s are very small numbers. For a better understanding of the results, the significant deviations of the angular velocity from a sound condition compared to the reference condition are additionally given in percentage (condition R = 100 %).

3.1 Gender-specific analysis

All results were gender-specific analyzed. A significant difference between females and males was observed for condition EP compared to the reference condition in medial-lateral direction for standing with eyes open in room LR (p = 0.012) (figure 1A). Female participants showed a higher body sway velocity compared to the reference (difference on average +0.05 °/s), whereas male participants showed a slightly lower body sway velocity (difference on average -0.02 °/s). Only for the female participants differed the body sway velocity significantly between condition R and EP (16.2 %, p = 0.011). Another significant gender-specific difference could be observed for walking over barriers in medial-lateral direction for condition iN (p = 0.004) (figure 1B). Male participants showed a significant lower body sway velocity compared to the recorded reference values (difference on average -1.12 °/s, -13.3 %, p = 0.001), whereas body sway velocity decreased statistically not significant for female participants compared to the reference condition (difference on average -0.04 °/s).

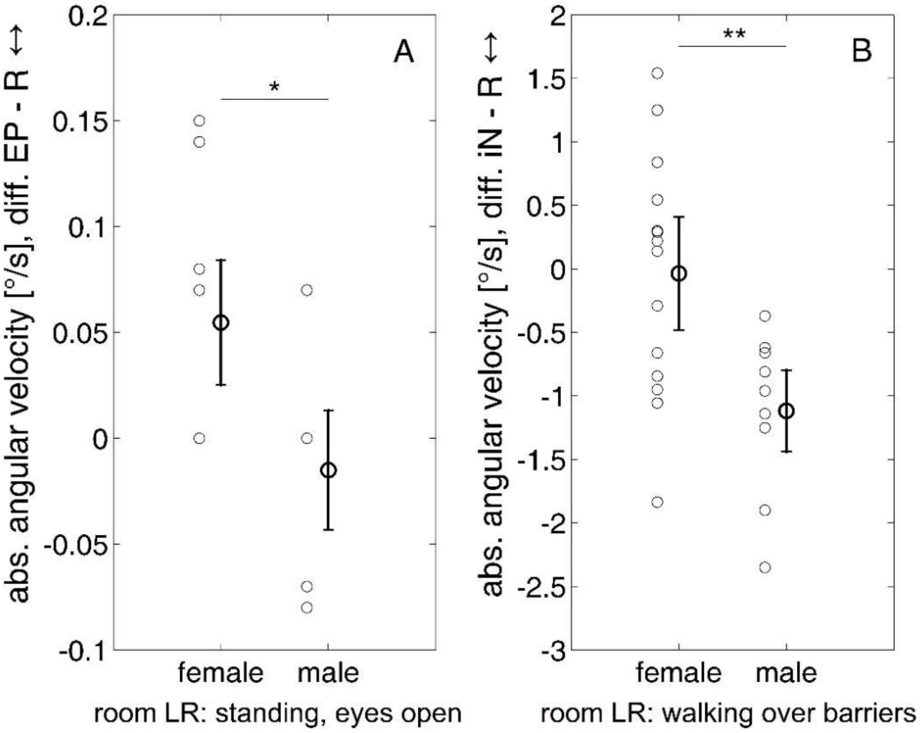


Figure 2: Gender-specific changes of angular velocities. Significant changes of angular velocity compared to the reference condition (R) for standing with opened eyes with ear protectors (EP) (A) and for walking over barriers in the interrupted noise (iN) condition (B) in medial-lateral direction (↔) for female and male participants in the room with a long reverberation time (LR). Standard deviation is shown by the vertical lines. Circles indicate individual values. Minus/plus means lower/higher angular velocities in the acoustic condition (EP or iN) than in the reference condition. Significance level: * ($p < 0.05$) or ** ($0.001 < p < 0.01$) (own figure)

3.2 Stance tasks

Significant changes of body sway velocity could be observed for all sound conditions in room LR and only for condition EP in room SR. The results of all measured conditions are shown in table 1 (room LR) and 2 (room SR).

In room LR, significantly increased sway velocity could be determined for continuously presented noise and when participants wore ear protectors compared to the reference condition. Standing on a firm ground with eyes open in anterior-posterior and medial-lateral direction (24.2 %, $p = 0.001$ or 26.8 %, $p = 0.009$, respectively) and standing on a firm ground with eyes closed in medial-lateral direction (19.7 %, $p = 0.004$) resulted in an increased body sway velocity when continuous noise was presented compared to condition R. An increased sway velocity could also be seen for standing on a firm ground with eyes closed in medial-lateral direction (13.8 %, p = 0.009) and standing on a foam support with eyes open in anterior-posterior direction (9.2 %, p = 0.015) for condition EP. Body sway velocity decreased only for presented interrupted noise when participants stood on a foam support with eyes closed in medial-lateral direction (-10.5 %, p = 0.007).

Table 1: Angular velocities of all stance tasks in the reverberant room. “Mean absolute angular velocities [°/s] and the standard deviations (italic) of all participants are shown for the tasks in the room with a long reverberation time. Arrows indicate medial-lateral (↔) and anterior-posterior (↕) direction. The reference condition (R) was compared with presented continuous (cN) or interrupted (iN) noise and wearing ear protectors (EP). A t-test for dependent samples or Wilcoxon test was applied. [Significant results are highlighted in blue.] The symbol ♀ indicates significance only for female participants.” (adapted and modified from Anton et al., 2019)

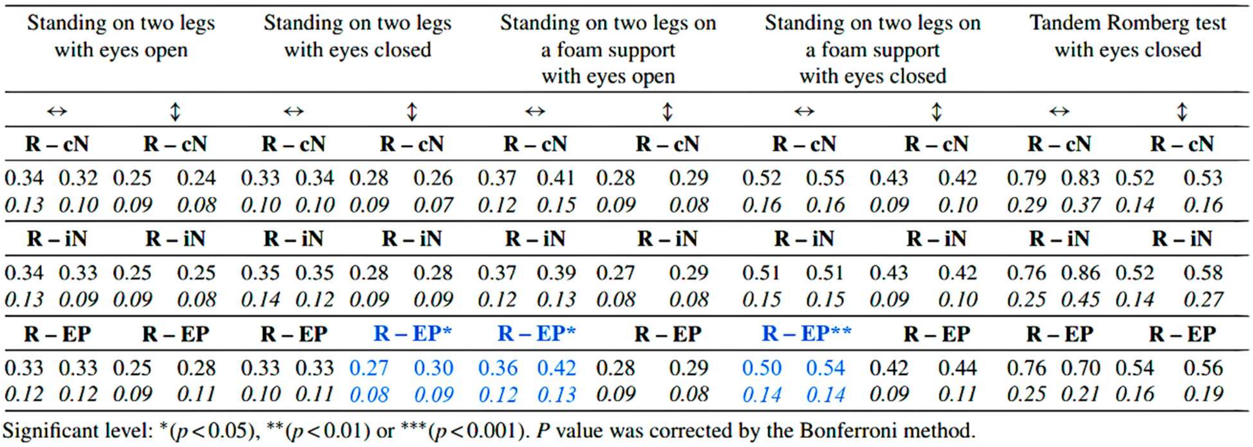
Standing on two legs with eyes open				Standing on two legs with eyes closed				Standing on two legs on a foam support with eyes open				Standing on two legs on a foam support with eyes closed				Tandem Romberg test with eyes closed			
↔		↕		↔		↕		↔		↕		↔		↕		↔		↕	
R – cN**		**R – cN****		**R – cN****		**R – cN**		**R – cN**		**R – cN**		**R – cN**		**R – cN**		**R – cN**		**R – cN**	
0.32	0.40	0.24	0.30	0.33	0.39	0.28	0.29	0.41	0.44	0.29	0.29	0.57	0.57	0.44	0.42	0.75	0.74	0.51	0.54
0.10	*0.17*	*0.08*	*0.10*	*0.12*	*0.11*	*0.10*	*0.09*	*0.10*	*0.13*	*0.07*	*0.07*	*0.17*	*0.15*	*0.10*	*0.09*	*0.26*	*0.25*	*0.18*	*0.14*
R – iN		**R – iN**		**R – iN**		**R – iN**		**R – iN**		**R – iN**		**R – iN****		**R – iN**		**R – iN**		**R – iN**	
0.32	0.33	0.25	0.27	0.33	0.33	0.27	0.28	0.40	0.43	0.30	0.32	0.57	0.51	0.43	0.45	0.72	0.72	0.48	0.50
0.10	*0.12*	*0.08*	*0.09*	*0.12*	*0.11*	*0.09*	*0.08*	*0.10*	*0.16*	*0.07*	*0.11*	*0.17*	*0.13*	*0.08*	*0.10*	*0.23*	*0.24*	*0.10*	*0.11*
R – EP*♀		**R – EP**		**R – EP****		**R – EP**		**R – EP**		**R – EP***		**R – EP**		**R – EP**		**R – EP**		**R – EP**	
0.32	0.35	0.24	0.26	0.29	0.33	0.27	0.29	0.41	0.44	0.30	0.32	0.57	0.57	0.44	0.45	0.75	0.71	0.50	0.51
0.09	*0.13*	*0.08*	*0.10*	*0.08*	*0.10*	*0.09*	*0.09*	*0.10*	*0.13*	*0.07*	*0.10*	*0.17*	*0.15*	*0.10*	*0.11*	*0.25*	*0.22*	*0.12*	*0.14*

Significant level: * ($p<0.05$), ** ($p<0.01$) or *** ($p<0.001$). *P* value was corrected by the Bonferroni method.

When participants were equipped with ear protectors in the room SR, body sway velocity increased significantly compared to condition R for standing on a firm ground with eyes closed (9.2 %, p = 0.013) in anterior-posterior direction and standing on a foam support with eyes open (15.2 %, p = 0.01) and closed (8.9 %, p = 0.008) in medial-lateral direction.

No significant changes in body sway velocity could be observed when participants performed the Tandem Romberg test in different acoustic conditions in both rooms.

Table 2: Angular velocities of all stance tasks in the anechoic room. “Mean absolute angular velocities [°/s] and the standard deviations (italic) of all participants are shown for the tasks in the room with a short reverberation time. Arrows indicate medial-lateral (↔) and anterior-posterior (↕) direction. The reference condition (R) was compared with presented continuous (cN) or interrupted (iN) noise and wearing ear protectors (EP). A t-test for dependent samples or Wilcoxon test was applied. [Significant results are highlighted in blue.]” (adapted and modified from Anton et al., 2019)



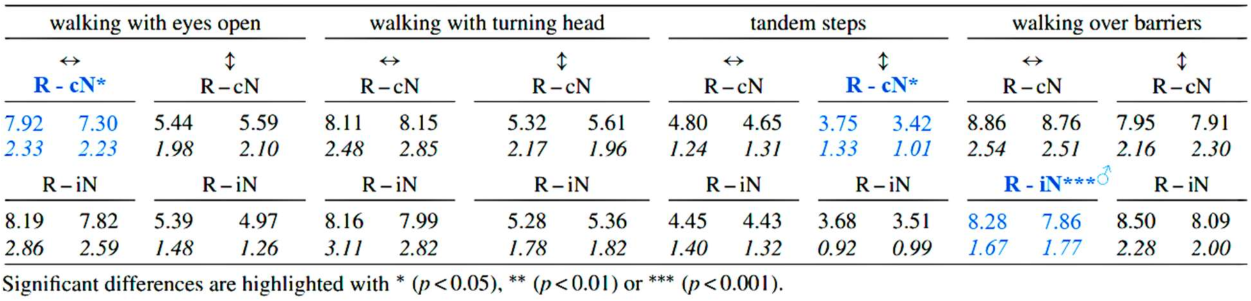
Standing on two legs with eyes open				Standing on two legs with eyes closed				Standing on two legs on a foam support with eyes open				Standing on two legs on a foam support with eyes closed				Tandem Romberg test with eyes closed			
↔		↕		↔		↕		↔		↕		↔		↕		↔		↕	
R – cN		**R – cN**		**R – cN**		**R – cN**		**R – cN**		**R – cN**		**R – cN**		**R – cN**		**R – cN**		**R – cN**	
0.34	0.32	0.25	0.24	0.33	0.34	0.28	0.26	0.37	0.41	0.28	0.29	0.52	0.55	0.43	0.42	0.79	0.83	0.52	0.53
0.13	*0.10*	*0.09*	*0.08*	*0.10*	*0.10*	*0.09*	*0.07*	*0.12*	*0.15*	*0.09*	*0.08*	*0.16*	*0.16*	*0.09*	*0.10*	*0.29*	*0.37*	*0.14*	*0.16*
R – iN		**R – iN**		**R – iN**		**R – iN**		**R – iN**		**R – iN**		**R – iN**		**R – iN**		**R – iN**		**R – iN**	
0.34	0.33	0.25	0.25	0.35	0.35	0.28	0.28	0.37	0.39	0.27	0.29	0.51	0.51	0.43	0.42	0.76	0.86	0.52	0.58
0.13	*0.09*	*0.09*	*0.08*	*0.14*	*0.12*	*0.09*	*0.09*	*0.12*	*0.13*	*0.08*	*0.08*	*0.15*	*0.15*	*0.09*	*0.10*	*0.25*	*0.45*	*0.14*	*0.27*
R – EP		**R – EP**		**R – EP**		**R – EP***		**R – EP***		**R – EP**		**R – EP****		**R – EP**		**R – EP**		**R – EP**	
0.33	0.33	0.25	0.28	0.33	0.33	0.27	0.30	0.36	0.42	0.28	0.29	0.50	0.54	0.42	0.44	0.76	0.70	0.54	0.56
0.12	*0.12*	*0.09*	*0.11*	*0.10*	*0.11*	*0.08*	*0.09*	*0.12*	*0.13*	*0.09*	*0.08*	*0.14*	*0.14*	*0.09*	*0.11*	*0.25*	*0.21*	*0.16*	*0.19*

Significant level: *($p < 0.05$), **($p < 0.01$) or ***($p < 0.001$). *P* value was corrected by the Bonferroni method.

3.3 Gait tasks

All results of the walking tasks are presented in table 3. In two comparisons participants swayed significantly slower when noise was continuously presented compared to the reference. This was true for walking with eyes open in medial-lateral direction (-7.8 %, p = 0.036) and tandem steps in anterior-posterior direction (-8.8 %, p = 0.029). There were no significant changes for walking with turning the head in rhythm, though the results showed a trend that angular velocity increased with presented noise.

Table 3: Angular velocities of all gait tasks. "Mean absolute angular velocity values [°/s] and the standard deviations (italic) of all participants are shown for all tasks. Arrows indicate medial-lateral (↔) and anterior-posterior (↕) direction. The reference condition (R) was compared with presented continuous (cN) or interrupted (iN) noise. A t-test for dependent samples or Wilcoxon test was applied. [Significant results are highlighted in blue. The symbol ♂ indicates significance only for male participants.]" (adapted and modified from Anton et al., 2021)



walking with eyes open				walking with turning head				tandem steps				walking over barriers			
↔		↕		↔		↕		↔		↕		↔		↕	
R - cN*		R – cN		R – cN		R – cN		R – cN		**R - cN***		R – cN		R – cN	
7.92	7.30	5.44	5.59	8.11	8.15	5.32	5.61	4.80	4.65	3.75	3.42	8.86	8.76	7.95	7.91
2.33	*2.23*	*1.98*	*2.10*	*2.48*	*2.85*	*2.17*	*1.96*	*1.24*	*1.31*	*1.33*	*1.01*	*2.54*	*2.51*	*2.16*	*2.30*
R – iN		R – iN		R – iN		R – iN		R – iN		R – iN		**R - iN***♂**		R – iN	
8.19	7.82	5.39	4.97	8.16	7.99	5.28	5.36	4.45	4.43	3.68	3.51	8.28	7.86	8.50	8.09
2.86	*2.59*	*1.48*	*1.26*	*3.11*	*2.82*	*1.78*	*1.82*	*1.40*	*1.32*	*0.92*	*0.99*	*1.67*	*1.77*	*2.28*	*2.00*

Significant differences are highlighted with * ($p < 0.05$), ** ($p < 0.01$) or *** ($p < 0.001$).

4. Discussion

Overall, auditory input such as white broadband noise has an impact on postural stability in stance and gait movement in healthy and normal hearing humans. Room acoustic, the presented sound and cognitive processes seem to play an important role to what extent auditory input influences postural stability. The gender hardly effects changes in postural control by changing the auditory input.

4.1 Gender-specific changes in posture

A gender-specific impact on postural control by changing the acoustic input could be seen in one out of 60 stance conditions and in one out of 16 gait conditions only. Female participants swayed faster with ear protectors versus the reference condition in the reverberant room during standing with opened eyes than male participants. One presumption could be that the male participants used spatial cues such as reflections for challenging standing exercises only, whereas female participants were already using them for simple exercises to maintain postural stability. A small gender-specific effect of sound on static balance tasks could be observed by Polechonski and Blaszczyk (2006). Females seemed to be slightly more sensitive to sound than men. Another explanation could be the different body height of females and males. Male participants were on average taller, wherefore the center of gravity was higher. This could lead to higher body sway and thus more sensorineural feedback from the vestibular system. A higher body sway of males compared to females in medial-lateral direction for standing with opened eyes was observed by Basta et al. (2013). Male participants aged between 20 and 39 years showed on average an angular velocity of 0.43 °/s, whereas the angular velocity of female participants was on average 0.36 °/s. In absence of spatial cues this could have helped males to maintain balance, whereas females received less sensorineural feedback from the vestibular system. An influence of body height or body center of mass on postural stability was observed in previous studies (Farenc et al., 2003; Hegeman et al., 2007; Rosker et al., 2011). In the gait condition, male participants improved balance in the interrupted noise condition in medial-lateral direction when walking over barriers, but females showed no improvement in this condition. Walking over barriers was potentially more difficult for female participants than for men because they were, on average, smaller. Thus, female participants could not improve their postural stability with presented interrupted noise, whereas men could improve their balance.

4.2 Impact of different auditory input and room properties on postural stability in stance tasks

In previous studies, force platforms or balance boards were mainly applied to determine ground reaction force, center of pressure of the feet and body sway velocity for standing tasks (Easton et al., 1998; Gandemer et al., 2014; Kanegaonkar et al., 2012; Ross et al., 2016; Seiwerth et al., 2020; Stevens et al., 2016; Vitkovic et al., 2016). In addition, recording time varied between 20-70 s in these studies. Carpenter and Campos (2020) recommend a recording time of at least 60 s for center of pressure/mass measurements to capture the low frequencies of sway behavior. However, in the present study we measured angular velocity in °/s, wherefore a recording time of 20 s is sufficient to captured changes in sway behavior by changing the auditory input. It was not investigated if the results of the measurement systems used in previous studies (e. g. force platform, video system, inertial or pressure sensors) correlate with the measured angular velocities by the VertiGuard system used in this study. The advantages of the VertiGuard system are the body sway velocity recording close to the body's center of gravity and the device worn on the body, so that the recordings are independent of the examination room. Furthermore, sway velocities of static and dynamic tasks can be recorded. Although, it is difficult to compare our results with other studies due to the different recording method, there are some similar findings.

Postural stability increased significantly in stance tasks when interrupted noise was presented in one out of 30 conditions in the room with a long reverberation time for a more difficult task (closed eyes, foam support). Though, postural stability decreased when continuous noise was presented or participants wore earplugs. In the room with a very short reverberation time, no benefit from presented sound could be observed, but postural stability decreased for tasks with reduced visual or proprioceptive input (closed eyes, foam support) when participants wore ear protectors. Participants in Kanegaonkar's et al. (2012) study showed higher body sway in a normal clinic room and in a soundproofed room with ear protectors versus without for standing tasks. In the study of Easton et al. (1998), no differences in postural stability were measured when participants performed the Tandem Romberg stance and sound was played from one loudspeaker from the front compared to silence in an ambient room with sound reflecting surfaces. No auditory influence on balance was observed during the Tandem Romberg test in this study. Though, participants swayed less in Easton et al. (1998) when noise was played from two loudspeakers placed closely in front of each ear compared to silence. Small changes in the distance between the loudspeaker and the ear can result in volume differences between both ears. This could have helped to improve balance. Gandemer et al. (2014) observed no difference in postural stability between silence and stationary sound in a soundproofed room. Though, a moving sound source improved balance. Seiwerth et al. (2020) also found no auditory influence on postural stability for standing tasks when sound was played from one speaker compared to wearing ear protectors in a hypoechoic, sound-insulated booth. But they found an auditory impact on postural regulations by postural subsystems such as the visual and vestibular system. Stevens et al. (2016), Vitkovic et al. (2016) and Zhong and Yost (2013) showed an improvement in postural control in noise condition versus silent. Though, room acoustic, position and number of loudspeaker(s), the stimulus and recording method varied.

Participants in the present study had no benefit from sound in the anechoic room or when wearing ear protector, but in the reverberating room interrupted sound improved balance, whereas ear protector and continuous noise negatively influenced postural stability in stance tasks. Given, that spatial reflections cannot be perceived when continuous noise is presented (due to masking) or when participants wear ear protectors, spatial reflections seem to have a positive influence on postural stability. In the interrupted noise condition, the required spatial reflections could be perceived in the 0.5 s pauses in the reverberant room, whereas reflections in the anechoic room were too short to perceive these in the pauses.

It is already known that spatial cues such as reflections and reverberations, number and position of speaker(s) and the presented stimulus, play an important role in localizing a sound source (Giguère and Abel, 1993; Ihlefeld and Shinn-Cunningham, 2011; Rakerd and Hartmann, 2010). A decisive factor for the localization ability is the first arriving sound, called precedence effect (Litovsky et al., 1999). The first arriving sound determines the direction the sound is coming from and therefore the localization of the sound source. Reverberations likely impair the localization of the first arriving sound. The localization ability might be therefore reduced in the reverberant room during the presentation of continuous noise as the first arriving sound could not be precisely localized, whereas the first arriving sound in the interrupted noise condition could be perceived more often due to the breaks and thus improve the localization ability. In the anechoic room, no balance improvement in the continuous noise condition was observed, although the first arriving sound was not overlaid by reverberations. The low background noise could already have been sufficient in the reference condition to improve balance, wherefore no further improvement in the continuous or interrupted noise condition could be observed.

4.3 Impact of different auditory and spatial cues on postural stability in gait tasks

In a few walking conditions, participants improved their postural control when noise was presented. This was true only for walking tasks with the head focused to the front/loudspeaker. No significant changes in postural stability was observed for turning the head in noise condition, but our data show a trend to a higher sway velocity when turning the head with presented noise compared to silence. The fixed sound source at the end of the walking distance and the fact that the participants walked towards the loudspeaker could have helped to localize the sound, although the reverberations potentially masked the first arriving sound. The closer the participants walked to the loudspeaker, the louder the sound became. As observed with standing tasks, the localization ability could improve postural stability also for walking tasks. Karim et al. (2018), Munnings et al. (2015), Seiwerth et al. (2018) and Zhong and Yost (2013) found similar results. Their participants performed the Fukuda stepping test (modified Unterberger test) (50 or 100 steps, eyes closed/blindfolded and arms outstretched) in silence and in noise played from a single loudspeaker placed in front. Participants in Karim et al. (2018) and Seiwerth et al. (2018) also used ear plugs in the quiet condition. The measured angle of the feet before and after the stepping test showed a significant smaller deviation when noise was presented compared to silence. It is likely that the localization of the sound source improved postural control. In Karim's et al. (2018) study, participants also performed the stepping test when noise was played through headphones. There were no significant changes in angular deviations between silence and the noise via headphone condition. This supports the assumption that spatial cues (reflections) or the localization ability are important to improve balance. Note that visual cues were kept to a minimum in these four studies, whereas participants in the presented study walked with opened eyes. The effect of localization in noise condition might have been greater in this study if participants had walked with their eyes closed. Though, participants would have had to overcome themselves walking the distance without seeing. It is likely that participants would have changed their kind of walking with closed eyes (e. g. speed, step length). The localization ability might be impaired when participants turned their head to the right and left during walking (in relation to the loudspeaker). Therefore, no significant benefit could be seen by providing sound in this task in the given condition.

Besides the localization ability, cognitive performances could also play a role in maintaining postural stability. Bonnet (2016) described a positive or negative influence on postural stability depending on attentional focus. For example, walking with moving the head demands multiple tasks. This walking task is more difficult in motoric and cognitive terms compared to the other walking tasks. The attention focus might be more on maintaining balance or walking, but not on hearing. In stance conditions, a similar effect could be observed for the Tandem Romberg test. Postural stability did not change in noise versus no noise condition. This task was more difficult than the other standing tasks. Some studies described a correlation between the cognitive demand of the task and body sway (Huxhold et al., 2006; Riley et al., 2003; Vuillerme and Nougier, 2004). In dual-task condition (e. g. walking with turning the head and listen to sound), participants had to share their cognitive resources as there is an additional competing need of attention. Postural stability might be reduced in dual-task condition as the cognitive demand increases and the remaining attention is insufficient to maintain balance (Li and Lindenberger, 2002; Nieborowska et al., 2019). In our study, participants walked, turned their head and listened to sound. This could have been very challenging from a cognitive or attention point of view. As a result, participants may not have been able to use the stationary sound source to improve balance in such a difficult task.

4.4 Strengths and weaknesses of this study

Balance influencing factors were precisely determined and monitored in this dissertation. All participants underwent several investigations to ensure that they meet the strict requirements (e. g. normal hearing, normal or corrected vision, normal vestibular system and balance). Pathological conditions that could affect the balance system were excluded. The room acoustic properties (e. g. reverberation time and background noise) were determined by a professional and the acoustic environment was monitored during all recordings. Angular velocities of the body during stance and gait tasks were recorded with a dynamic posturography system that provides a high measurement accuracy. Due to the homogeneity of the participants, the monitoring of the acoustic conditions and exercise performances, the results can be assumed to be reliable. The results match the existing literature and provide an important contribution, especially the findings of the gait tasks.

Participants’ cognitive performance during the tasks was not assessed. This could have led to a better understanding of the different observations for the cognitively more difficult tasks compared to the easier tasks. Furthermore, the localization ability could have been determined in both rooms to reinforce the explanation of the results.

5. Conclusion and outlook

Although, balance in healthy humans seems to be not as much affected by the auditory system as it is by the visual, proprioceptive and vestibular system, the room acoustic, the stimulus signal and the cognitive performance play an important role. A clear standard for the acoustic environment during balance recordings cannot be defined, but some general useful recommendations can be made. In clinical routine, balance measurement should be performed in a normal clinic room and not in a strong reverberant or anechoic room as the long reverberations or the lack of reflections could influence the balance performance. Static and dynamic balance measurements are usually recorded over several seconds. During that time, the acoustic environment should be kept constant without any external sound source (e. g. devices that generate noise). A sound source during balance measurements could falsify the results (e. g. improves balance due to the localization of the sound source or clearly audible noises could mask useful reflections in order to maintain balance). Such devices should be turned off or removed. Conversations or calls should also be avoided. This could in addition distract the patient from the balancing task that requires attention. Particularly in the case of measurements that are repeated and compared, the acoustic environment should be constant in all sessions.

In future studies, the influence of auditory cues in hearing and vestibular impaired patients should be investigated in more detail, especially the influence of hearing devices and their noise reduction features. Furthermore, the etiology and the effected parts of the hearing and vestibular systems should be precisely determined. On the one hand, a sound source could improve postural stability and on the other hand, a noisy environment could mask useful spatial cues. This raises the question of whether noise reduction features in hearing devices could affect balance. Vestibular and hearing impairment often go hand in hand (Newman-Toker et al., 2016). Furthermore, an increased postural imbalance and risk of falling could already be associated with hearing impairment (Agmon et al., 2017; Chen et al., 2015; Jiam et al., 2016; Viljanen et al., 2009). Patients with an impaired inner ear might benefit more from auditory input than healthy people (Ernst et al., 2021; Maheu et al., 2019). A positive impact on balance could already be observed for hearing impaired patients with their hearing devices turned on versus off (Ibrahim et al., 2019; Negahban et al., 2017; Rumalla et al., 2015; Shayman et al., 2017; Vitkovic et al., 2016; Weaver et al., 2017). Similar could be observed for vestibular impaired patients in noise condition versus silence (Stevens et al., 2016; Vitkovic et al., 2016). Although, fitting of hearing devices focuses on improvement of speech perception in different listening situations (Ernst et al., 2019; Geißler et al., 2015; Popelka and Moore, 2016; Skinner, 2003), if, however, a significant improvement in postural control in hearing-impaired patients (with or without vestibular vertigo) is possible, e. g. by a specific hearing device fitting, this should be considered for treatment in order to reduce the risk of falls.

Bibliography

Agmon, M., Lavie, L., & Doumas, M. (2017). The association between hearing loss, postural control, and mobility in older adults: A systematic review. *Journal of the American Academy of Audiology, 28*(6), 575–588. https://doi.org/10.3766/jaaa.16044

Altissimi, G., Colizza, A., Cianfrone, G., de Vincentiis, M., Greco, A., Taurone, S., Musacchio, A., Ciofalo, A., Turchetta, R., Angeletti, D., & Ralli, M. (2020). Drugs inducing hearing loss, tinnitus, dizziness and vertigo: An updated guide. *European Review for Medical and Pharmacological Sciences, 24*(15), 7946–7952. https://doi.org/10.26355/eurrev_202008_22477

Anton, K., Ernst, A., & Basta, D. (2019). Auditory influence on postural control during stance tasks in different acoustic conditions. *Journal of Vestibular Research, 29*(6), 287–294. https://doi.org/10.3233/ves-190674

Anton, K., Ernst, A., & Basta, D. (2021). A static sound source can improve postural stability during walking. *Journal of Vestibular Research, 31*(3), 143–149. https://doi.org/10.3233/ves-200015

Barker, M., Solinski, H. J., Hashimoto, H., Tagoe, T., Pilati, N., & Hamann, M. (2012). Acoustic overexposure increases the expression of VGLUT-2 mediated projections from the lateral vestibular nucleus to the dorsal cochlear nucleus. *PloS ONE, 7*(5), Article e35955. https://doi.org/10.1371/journal.pone.0035955

Basta, D., Todt, I., Goepel, F., & Ernst, A. (2008). Loss of saccular function after cochlear implantation: The diagnostic impact of intracochlear electrically elicited vestibular evoked myogenic potentials. *Audiology & Neurotology, 13*(3), 187–192. https://doi.org/10.1159/000113509

Basta, D., Rossi-Izquierdo, M., Soto-Varela, A., & Ernst, A. (2013). Mobile posturography: Posturographic analysis of daily-life mobility. *Otology & Neurotology, 34*(2), 288–297. https://doi.org/10.1097/mao.0b013e318277a29b

Baumann, O., & Mattingley, J. B. (2010). Scaling of neural responses to visual and auditory motion in the human cerebellum. *The Journal of Neuroscience, 30*(12), 4489–4495. https://doi.org/10.1523/jneurosci.5661-09.2010

Belmont, J. W., Craigen, W., Martinez, H., & Jefferies, J. L. (2011). Genetic disorders with both hearing loss and cardiovascular abnormalities. *Advances in Oto-Rhino-Laryngology, 70*, 66–74. https://doi.org/10.1159/000322474

Bertholon, P., & Karkas, A. (2016). Otologic disorders causing dizziness, including surgery for vestibular disorders. *Handbook of Clinical Neurology, 137*, 279–293. https://doi.org/10.1016/b978-0-444-63437-5.00020-0

Bonnet C. T. (2016). Advantages and disadvantages of stiffness instructions when studying postural control. *Gait & Posture, 46*, 208–210. https://doi.org/10.1016/j.gaitpost.2015.12.026

Bronstein, A. M., Golding, J. F., Gresty, M. A., Mandalà, M., Nuti, D., Shetye, A., & Silove, Y. (2010). The social impact of dizziness in London and Siena. *Journal of Neurology, 257*(2), 183–190. https://doi.org/10.1007/s00415-009-5287-z

Bukowska D. (2002). Morphological evidence for secondary vestibular afferent connections to the dorsal cochlear nucleus in the rabbit. *Cells, Tissues, Organs, 170*(1), 61–68. https://doi.org/10.1159/000047921

Burian, M., & Gstoettner, W. (1988). Projection of primary vestibular afferent fibres to the cochlear nucleus in the guinea pig. *Neuroscience Letters, 84*(1), 13–17. https://doi.org/10.1016/0304-3940(88)90329-1

Carpenter, M. G., & Campos, J. L. (2020). The effects of hearing loss on balance: A critical review. *Ear and Hearing, 41* (Suppl 1), 107S–119S. https://doi.org/10.1097/aud.0000000000000929

Chen, D. S., Betz, J., Yaffe, K., Ayonayon, H. N., Kritchevsky, S., Martin, K. R., Harris, T. B., Purchase-Helzner, E., Satterfield, S., Xue, Q. L., Pratt, S., Simonsick, E. M., Lin, F. R., & Health ABC study (2015). Association of hearing impairment with declines in physical functioning and the risk of disability in older adults. *The Journals of Gerontology: Series A, 70*(5), 654–661. https://doi.org/10.1093/gerona/glu207

Cohen, B. E., Durstenfeld, A., & Roehm, P. C. (2014). Viral causes of hearing loss: A review for hearing health professionals. *Trends in Hearing, 18*, 1–17. https://doi.org/10.1177/2331216514541361

Coordes, A., Basta, D., Götze, R., Scholz, S., Seidl, R. O., Ernst, A., & Todt, I. (2012). Sound-induced vertigo after cochlear implantation. *Otology & Neurotology, 33*(3), 335–342. https://doi.org/10.1097/mao.0b013e318245cee3

Dawes, P., Emsley, R., Cruickshanks, K. J., Moore, D. R., Fortnum, H., Edmondson-Jones, M., McCormack, A., & Munro, K. J. (2015). Hearing loss and cognition: The role of hearing aids, social isolation and depression. *PloS ONE, 10*(3), Article e0119616. https://doi.org/10.1371/journal.pone.0119616

Deviterne, D., Gauchard, G. C., Jamet, M., Vançon, G., & Perrin, P. P. (2005). Added cognitive load through rotary auditory stimulation can improve the quality of postural control in the elderly. *Brain Research Bulletin, 64*(6), 487–492. https://doi.org/10.1016/j.brainresbull.2004.10.007

Easton, R. D., Greene, A. J., DiZio, P., & Lackner, J. R. (1998). Auditory cues for orientation and postural control in sighted and congenitally blind people. *Experimental Brain Research, 118*(4), 541–550. https://doi.org/10.1007/s002210050310

El-Badry, M. M., Abousetta, A., & Kader, R. M. A. (2015). Vestibular dysfunction in patients with post-mumps sensorineural hearing loss. *The Journal of Laryngology & Otology, 129*(4), 337–341. https://doi.org/10.1017/S0022215115000511

Enticott, J. C., Tari, S., Koh, S. M., Dowell, R. C., & O'Leary, S. J. (2006). Cochlear implant and vestibular function. *Otology & Neurotology, 27*(6), 824–830. https://doi.org/10.1097/01.mao.0000227903.47483.a6

Ernst, A., Anton, K., Brendel, M., & Battmer, R. D. (2019). Benefit of directional microphones for unilateral, bilateral and bimodal cochlear implant users. *Cochlear Implants International, 20*(3), 147–157. https://doi.org/10.1080/14670100.2019.1578911

Ernst, A., Basta, D., Mittmann, P., & Seidl, R. O. (2021). Can hearing amplification improve presbyvestibulopathy and/or the risk-to-fall? *European Archives of Oto-Rhino-Laryngology, 278*(8), 2689–2694. https://doi.org/10.1007/s00405-020-06414-9

Esparza, C. M., Jáuregui-Renaud, K., Morelos, C. M., Muhl, G. E., Mendez, M. N., Carillo, N. S., Bello, N. S., & Cardenas, M. (2007). Systemic high blood pressure and inner ear dysfunction: a preliminary study. *Clinical Otolaryngology, 32*(3), 173–178. https://doi.org/10.1111/j.1365-2273.2007.01442.x

Farenc, I., Rougier, P., & Berger, L. (2003). The influence of gender and body characteristics on upright stance. *Annals of Human Biology, 30*(3), 279–294. https://doi.org/10.1080/0301446031000068842

Fitzgerald, D. C. (1996). Head trauma: Hearing loss and dizziness. *The Journal of Trauma, 40*(3), 488–496. https://doi.org/10.1097/00005373-199603000-00034

Gandemer, L., Parseihian, G., Kronland-Martinet, R., & Bourdin, C. (2014). The influence of horizontally rotating sound on standing balance. *Experimental Brain Research, 232*(12), 3813–3820. https://doi.org/10.1007/s00221-014-4066-y

Geißler, G., Arweiler, I., Hehrmann, P., Lenarz, T., Hamacher, V., & Büchner, A. (2015). Speech reception threshold benefits in cochlear implant users with an adaptive beamformer in real life situations. *Cochlear Implants International, 16*(2), 69–76. https://doi.org/10.1179/1754762814y.0000000088

Giguère, C., & Abel, S. M. (1993). Sound localization: effects of reverberation time, speaker array, stimulus frequency, and stimulus rise/decay. *The Journal of the Acoustical Society of America, 94*(2 Pt 1), 769–776. https://doi.org/10.1121/1.408206

Grasby, P. M., Frith, C. D., Friston, K. J., Bench, C., Frackowiak, R. S. J., & Dolan, R. J. (1993). Functional mapping of brain areas implicated in auditory – verbal memory function. *Brain, 116* (Pt 1), 1–20. https://doi.org/10.1093/brain/116.1.1

Hänsel, T., Gauger, U., Bernhard, N., Behzadi, N., Romo Ventura, M. E., Hofmann, V., Olze, H., Knopke, S., Todt, I., & Coordes, A. (2018). Meta-analysis of subjective complaints of vertigo and vestibular tests after cochlear implantation. *The Laryngoscope, 128*(9), 2110–2123. https://doi.org/10.1002/lary.27071

Hegeman, J., Shapkova, E. Y., Honegger, F., & Allum, J. H. (2007). Effect of age and height on trunk sway during stance and gait. *Journal of Vestibular Research, 17*(2-3), 75–87.

Huang, C. M., Liu, G., & Huang, R. (1982). Projections from the cochlear nucleus to the cerebellum. *Brain Research, 244*(1), 1–8. https://doi.org/10.1016/0006-8993(82)90897-6

Huxhold, O., Li, S. C., Schmiedek, F., & Lindenberger, U. (2006). Dual-tasking postural control: aging and the effects of cognitive demand in conjunction with focus of attention. *Brain Research Bulletin, 69*(3), 294–305. https://doi.org/10.1016/j.brainresbull.2006.01.002

Ibrahim, I., da Silva, S. D., Segal, B., & Zeitouni, A. (2019). Postural stability: assessment of auditory input in normal hearing individuals and hearing aid users. *Hearing, Balance and Communication, 17*(4), 280–287. https://doi.org/10.1080/21695717.2019.1630983

Ihlefeld, A., & Shinn-Cunningham, B. G. (2011). Effect of source spectrum on sound localization in an everyday reverberant room. *The Journal of the Acoustical Society of America, 130*(1), 324–333. https://doi.org/10.1121/1.3596476

ISO 7029:2000 Acoustics – Statistical distribution of hearing thresholds as a function of age.

Jiam, N. T., Li, C., & Agrawal, Y. (2016). Hearing loss and falls: A systematic review and meta-analysis. *The Laryngoscope, 126*(11), 2587–2596. https://doi.org/10.1002/lary.25927

Kanegaonkar, R. G., Amin, K., & Clarke, M. (2012). The contribution of hearing to normal balance. *The Journal of Laryngology & Otology, 126*(10), 984–988. https://doi.org/10.1017/s002221511200179x

Karim, A. M., Rumalla, K., King, L. A., & Hullar, T. E. (2018). The effect of spatial auditory landmarks on ambulation. *Gait & Posture, 60*, 171–174. https://doi.org/10.1016/j.gaitpost.2017.12.003

Klenzner, T., Neumann, M., Aschendorff, A., & Laszig, R. (2004). Caloric stimulation of the vestibular organ after cochlear implant surgery. *Laryngorhinootologie, 83*(10), 659–664. https://doi.org/10.1055/s-2004-825678

Krause, E., Louza, J. P., Wechtenbruch, J., & Gürkov, R. (2010). Influence of cochlear implantation on peripheral vestibular receptor function. *Otolaryngology – Head and Neck Surgery, 142*(6), 809–813. https://doi.org/10.1016/j.otohns.2010.01.017

Krüger, M., Schulte, M., Zokoll, M. A., Wagener, K. C., Meis, M., Brand, T., & Holube, I. (2017). Relation Between Listening Effort and Speech Intelligibility in Noise. *American Journal of Audiology, 26*(3S), 378–392. https://doi.org/10.1044/2017_aja-16-0136

Kubo, T., Yamamoto, K., Iwaki, T., Doi, K., & Tamura, M. (2001). Different forms of dizziness occurring after cochlear implant. *European Archives of Oto-Rhino-Laryngology, 258*(1), 9–12. https://doi.org/10.1007/pl00007519

Lane, J. I., Witte, R. J., Bolster, B., Bernstein, M. A., Johnson, K., & Morris, J. (2008). State of the art: 3T imaging of the membranous labyrinth. *American Journal of Neuroradiology, 29*(8), 1436–1440. https://doi.org/10.3174/ajnr.A1036

Li, K. Z. H., & Lindenberger, U. (2002). Relations between aging sensory/sensorimotor and cognitive functions. *Neuroscience and Biobehavioral Reviews, 26*(7), 777–783. https://doi.org/10.1016/s0149-7634(02)00073-8

Limb, C. J., Francis, H. F., Lustig, L. R., Niparko, J. K., & Jammal, H. (2005). Benign positional vertigo after cochlear implantation. *Otolaryngology – Head and Neck Surgery, 132*(5), 741–745. https://doi.org/10.1016/j.otohns.2005.01.004

Litovsky, R. Y., Colburn, H. S., Yost, W. A., & Guzman, S. J. (1999). The precedence effect. *The Journal of the Acoustical Society of America, 106*(4 Pt 1), 1633–1654. https://doi.org/10.1121/1.427914

Maheu, M., Behtani, L., Nooristani, M., Houde, M. S., Delcenserie, A., Leroux, T., & Champoux, F. (2019). Vestibular function modulates the benefit of hearing aids in people with hearing loss during static postural control. *Ear and Hearing, 40*(6), 1418–1424. https://doi.org/10.1097/aud.0000000000000720

Mendel, B., Bergenius, J., & Langius, A. (1999). Dizziness symptom severity and impact on daily living as perceived by patients suffering from peripheral vestibular disorder. *Clinical Otolaryngology & Allied Sciences, 24*(4), 286–293. https://doi.org/10.1046/j.1365-2273.1999.00261.x

Monzani, D., Casolari, L., Guidetti, G., & Rigatelli, M. (2001). Psychological distress and disability in patients with vertigo. *Journal of Psychosomatic Research, 50*(6), 319–323. https://doi.org/10.1016/s0022-3999(01)00208-2

Munnings, A., Chisnall, B., Oji, S., Whittaker, M., & Kanegaonkar, R. (2015). Environmental factors that affect the Fukuda stepping test in normal participants. *The Journal of Laryngology & Otology, 129*(5), 450–453. https://doi.org/10.1017/S0022215115000560

Negahban, H., Bavarsad Cheshmeh Ali, M., & Nassadj, G. (2017). Effect of hearing aids on static balance function in elderly with hearing loss. *Gait & Posture, 58*, 126–129. https://doi.org/10.1016/j.gaitpost.2017.07.112

Neuhauser, H. K., Radtke, A., von Brevern, M., Lezius, F., Feldmann, M., & Lempert, T. (2008). Burden of dizziness and vertigo in the community. *Archives of Internal Medicine, 168*(19), 2118–2124. https://doi.org/10.1001/archinte.168.19.2118

Newman-Toker, D. E., Della Santina, C. C. D., & Blitz, A. M. (2016). Vertigo and hearing loss. *Handbook of Clinical Neurology, 136*, 905–921. https://doi.org/10.1016/b978-0-444-53486-6.00046-6

Nieborowska, V., Lau, S. T., Campos, J., Pichora-Fuller, M. K., Novak, A., & Li, K. Z. H. (2019). Effects of Age on Dual-Task Walking While Listening. *Journal of Motor Behavior, 51*(4), 416–427. https://doi.org/10.1080/00222895.2018.1498318

Olusanya, B. O., Davis, A. C., & Hoffman, H. J. (2019). Hearing loss: Rising prevalence and impact. *Bulletin of the World Health Organization, 97*(10), 646–646A. https://doi.org/10.2471/blt.19.224683

Petacchi, A., Laird, A. R., Fox, P. T., & Bower, J. M. (2005). Cerebellum and auditory function: an ALE meta-analysis of functional neuroimaging studies. *Human Brain Mapping, 25*(1), 118–128. https://doi.org/10.1002/hbm.20137

Pichora-Fuller, M. K., Kramer, S. E., Eckert, M. A., Edwards, B., Hornsby, B. W., Humes, L. E., Lemke, U., Lunner, T., Matthen, M., Mackersie, C. L., Naylor, G., Phillips, N. A., Richter, M., Rudner, M., Sommers, M. S., Tremblay, K. L., & Wingfield, A. (2016). Hearing impairment and cognitive energy: The framework for understanding effortful listening (FUEL). *Ear and Hearing, 37* (Suppl 1), 5S–27S. https://doi.org/10.1097/aud.0000000000000312

Polechonski, J., & Blaszczyk, J. (2006). The effect of acoustic noise on postural sway in male and female subjects. *Journal of Human Kinetics, 15*, 37-52.

Popelka, G. R., & Moore, B. C. J. (2016). Future directions for hearing aid development. In G. Popelka, B. Moore, R. Fay, & A. Popper (Eds.), *Hearing Aids.* (Vol. 56., pp. 323-333), Springer Handbook of Auditory Research, Cham. https://doi.org/10.1007/978-3-319-33036-5_11

Rakerd, B., & Hartmann, W. M. (2010). Localization of sound in rooms. V. Binaural coherence and human sensitivity to interaural time differences in noise. *The Journal of the Acoustical Society of America, 128*(5), 3052–3063. https://doi.org/10.1121/1.3493447

Ribeiro, F., Zhang, C., Florêncio, D. A., & Ba, D. E. (2010). Using reverberation to improve range and elevation discrimination for small array sound source localization. *IEEE Transactions on Audio, Speech, and Language Processing, 18*(7), 1781-1792. https://doi.org/10.1109/TASL.2010.2052250

Riley, M. A., Baker, A. A., & Schmit, J. M. (2003). Inverse relation between postural variability and difficulty of a concurrent short-term memory task. *Brain Research Bulletin, 62*(3), 191–195. https://doi.org/10.1016/j.brainresbull.2003.09.012

Rosker, J., Markovic, G., & Sarabon, N. (2011). Effects of vertical center of mass redistribution on body sway parameters during quiet standing. *Gait & Posture, 33*(3), 452–456. https://doi.org/10.1016/j.gaitpost.2010.12.023

Ross, J. M., Will, O. J., McGann, Z., & Balasubramaniam, R. (2016). Auditory white noise reduces age-related fluctuations in balance. *Neuroscience Letters, 630*, 216–221. https://doi.org/10.1016/j.neulet.2016.07.060

Rumalla, K., Karim, A. M., & Hullar, T. E. (2015). The effect of hearing aids on postural stability. *The Laryngoscope, 125*(3), 720–723. https://doi.org/10.1002/lary.24974

Saha, K. (2021). Vertigo Related to Central Nervous System Disorders. *Continuum: Lifelong Learning in Neurology, 27*(2), 447–467. https://doi.org/10.1212/con.0000000000000933

Seiwerth, I., Jonen, J., Rahne, T., Lauenroth, A., Hullar, T. E., Plontke, S. K., & Schwesig, R. (2020). Postural regulation and stability with acoustic input in normal-hearing subjects. *HNO, 68*(Suppl 2), 100–105. https://doi.org/10.1007/s00106-020-00846-9

Seiwerth, I., Jonen, J., Rahne, T., Schwesig, R., Lauenroth, A., Hullar, T. E., & Plontke, S. K. (2018). Influence of hearing on vestibulospinal control in healthy subjects. *HNO, 66*(Suppl 2), 49–55. https://doi.org/10.1007/s00106-018-0520-7

Shayman, C. S., Earhart, G. M., & Hullar, T. E. (2017). Improvements in gait with hearing aids and cochlear implants. *Otology & Neurotology, 38*(4), 484–486. https://doi.org/10.1097/mao.0000000000001360

Skinner, M. W. (2003). Optimizing cochlear implant speech performance. Annals of Otology, Rhinology & Laryngology, 112(Suppl 9), 4-13. https://doi.org/10.1177/00034894031120s903

Snider, R. S., & Stowell, A. (1944). Receiving areas of the tactile, auditory, and visual systems in the cerebellum. *Journal of Neurophysiology, 7*(6), 331-357. https://doi.org/10.1152/jn.1944.7.6.331

Stevens, M. N., Barbour, D. L., Gronski, M. P., & Hullar, T. E. (2016). Auditory contributions to maintaining balance. *Journal of Vestibular Research, 26*(5-6), 433–438. https://doi.org/10.3233/ves-160599

Swartz, R., & Longwell, P. (2005). Treatment of vertigo. *American Family Physician, 71*(6), 1115–1122.

Tinetti, M. E., & Williams, C. S. (1997). Falls, injuries due to falls, and the risk of admission to a nursing home. *The New England Journal of Medicine, 337*(18), 1279–1284. https://doi.org/10.1056/nejm199710303371806

Todt, I., Basta, D., & Ernst, A. (2008). Does the surgical approach in cochlear implantation influence the occurrence of postoperative vertigo? *Otolaryngology – Head and Neck Surgery, 138*(1), 8–12. https://doi.org/10.1016/j.otohns.2007.09.003

van der Westhuizen, Y., Swanepoel, D. W., Heinze, B., & Hofmeyr, L. M. (2013). Auditory and otological manifestations in adults with HIV/AIDS. *International Journal of Audiology, 52*(1), 37–43. https://doi.org/10.3109/14992027.2012.721935

Viljanen, A., Kaprio, J., Pyykkö, I., Sorri, M., Pajala, S., Kauppinen, M., Koskenvuo, M., & Rantanen, T. (2009). Hearing as a predictor of falls and postural balance in older female twins. *The Journals of Gerontology: Series A,* 64A(2), 312–317. https://doi.org/10.1093/gerona/gln015

Vitkovic, J., Le, C., Lee, S. L., & Clark, R. A. (2016). The contribution of hearing and hearing loss to balance control. *Audiology & Neurotology, 21*(4), 195–202. https://doi.org/10.1159/000445100

Vuillerme, N., & Nougier, V. (2004). Attentional demand for regulating postural sway: The effect of expertise in gymnastics. *Brain Research Bulletin, 63*(2), 161–165. https://doi.org/10.1016/j.brainresbull.2004.02.006

Walther L. E. (2017). Current diagnostic procedures for diagnosing vertigo and dizziness. GMS Current Topics in Otorhinolaryngology – Head and Neck Surgery, 16, Doc02. https://doi.org/10.3205/cto000141

Wang, X. F., Woody, C. D., Chizhevsky, V., Gruen, E., & Landeira-Fernandez, J. (1991). The dentate nucleus is a short-latency relay of a primary auditory transmission pathway. *Neuroreport, 2*(7), 361–364. https://doi.org/10.1097/00001756-199107000-00001

Weaver, T. S., Shayman, C. S., & Hullar, T. E. (2017). The Effect of Hearing Aids and Cochlear Implants on Balance During Gait. *Otology & Neurotology, 38*(9), 1327–1332. https://doi.org/10.1097/mao.0000000000001551

Wolfe J. W. (1972). Responses of the cerebellar auditory area to pure tone stimuli. *Experimental Neurology, 36*(2), 295–309. https://doi.org/10.1016/0014-4886(72)90025-8

Zhong, X., & Yost, W. A. (2013). Relationship between postural stability and spatial hearing. *Journal of the American Academy of Audiology, 24*(9), 782–788. https://doi.org/10.3766/jaaa.24.9.3

Eidesstattliche Versicherung

Ich, Kristina Anton, versichere an Eides statt durch meine eigenhändige Unterschrift, dass ich die vorgelegte Dissertation mit dem Thema: Zentralnervöse Integration auditiver und vestibulärer Informationen / Central nervous integration of auditory and vestibular information selbstständig und ohne nicht offengelegte Hilfe Dritter verfasst und keine anderen als die angegebenen Quellen und Hilfsmittel genutzt habe.

Alle Stellen, die wörtlich oder dem Sinne nach auf Publikationen oder Vorträgen anderer Autoren/innen beruhen, sind als solche in korrekter Zitierung kenntlich gemacht. Die Abschnitte zu Methodik (insbesondere praktische Arbeiten, Laborbestimmungen, statistische Aufarbeitung) und Resultaten (insbesondere Abbildungen, Graphiken und Tabellen) werden von mir verantwortet.

Ich versichere ferner, dass ich die in Zusammenarbeit mit anderen Personen generierten Daten, Datenauswertungen und Schlussfolgerungen korrekt gekennzeichnet und meinen eigenen Beitrag sowie die Beiträge anderer Personen korrekt kenntlich gemacht habe (siehe Anteilserklärung). Texte oder Textteile, die gemeinsam mit anderen erstellt oder verwendet wurden, habe ich korrekt kenntlich gemacht.

Meine Anteile an etwaigen Publikationen zu dieser Dissertation entsprechen denen, die in der untenstehenden gemeinsamen Erklärung mit dem/der Erstbetreuer/in, angegeben sind. Für sämtliche im Rahmen der Dissertation entstandenen Publikationen wurden die Richtlinien des ICMJE (International Committee of Medical Journal Editors; www.icmje.og) zur Autorenschaft eingehalten. Ich erkläre ferner, dass ich mich zur Einhaltung der Satzung der Charité – Universitätsmedizin Berlin zur Sicherung Guter Wissenschaftlicher Praxis verpflichte.

Weiterhin versichere ich, dass ich diese Dissertation weder in gleicher noch in ähnlicher Form bereits an einer anderen Fakultät eingereicht habe.

Die Bedeutung dieser eidesstattlichen Versicherung und die strafrechtlichen Folgen einer unwahren eidesstattlichen Versicherung (§§156, 161 des Strafgesetzbuches) sind mir bekannt und bewusst.

Datum

Unterschrift

Anteilserklärung an den erfolgten Publikationen

Kristina Anton hatte folgenden Anteil an den folgenden Publikationen:

Publikation 1: **Anton, K.**, Ernst, A., & Basta, D. (2019). Auditory influence on postural control during stance tasks in different acoustic conditions. *Journal of Vestibular Research, 29*(6), 287-294. https://doi.org/10.3233/ves-190674

Beitrag im Einzelnen: Ich, Kristina Anton, entwickelte zusammen mit Priv.-Doz. Dr. rer. nat. Dietmar Basta und Prof. Dr. med. Arne Ernst das Studiendesign und den Versuchsaufbau. Dazu gehörte die Entwicklung der Fragestellung, die Bestimmung der Ein- und Ausschlusskriterien für die Probanden, die Auswahl der Voruntersuchungen, die Bestimmung der Messbedingungen und die Zusammenstellung der Testbatterie. Die praktische Umsetzung des Versuchsaufbaus erfolgte durch mich. Ich rekrutierte die Probanden, organisierte die Termine und führte alle Voruntersuchungen und Versuche durch. Zu den Voruntersuchungen gehörten die Bestimmung des Hör-, Seh- und Gleichgewichtsvermögens (Tonaudiometrie, Landolt-Sehtest, Standard-Balance-Defizit-Test, Messung der subjektiv haptischen Vertikalen und der zervikal vestibulär evozierten myogenen Potentiale, Kopf-Impuls-Test), die Erfassung möglichen Schwindels mittels eines Fragebogens (Dizziness Handicap Inventory) und eine Anamnese. Die Versuche beinhalten den Aufbau und die Kalibrierung des Messsystems, die Einweisung und Vorbereitung der Probanden und die Messung der Winkelgeschwindigkeiten bei verschiedenen Stehübungen unter verschiedenen akustischen Bedingungen. Außerdem verarbeitete und analysierte ich die Messergebnisse mittels diverser Software (u. a. MATLAB, Audacity, VLC Media Player, Microsoft Excel). Dabei mussten alle Aufnahmen akustisch und visuell geprüft und die Messungen der Winkelgeschwindigkeiten mit den Videoaufnahmen zusammengeführt werden. Des Weiteren führte ich die statistischen Analysen mittels IBM SPSS durch und erstellte die Datenvisualisierung mit Hilfe von MATLAB. Aus meinen statistischen Auswertungen sind alle Abbildungen (Abb. 1-3) und alle Tabellen (Tab. 1, 2) entstanden. Zusammen mit Priv.-Doz. Dr. rer. nat. Dietmar Basta interpretierte ich die Ergebnisse. Ich schrieb die erste Fassung des Manuskriptes und arbeitete die gewünschten Korrekturen der Gutachter ein.

Publikation 2: **Anton, K.**, Ernst, A., & Basta, D. (2021). A static sound source can improve postural stability during walking. *Journal of Vestibular Research, 31*(3), 143-149. https://doi.org/10.3233/ves-200015

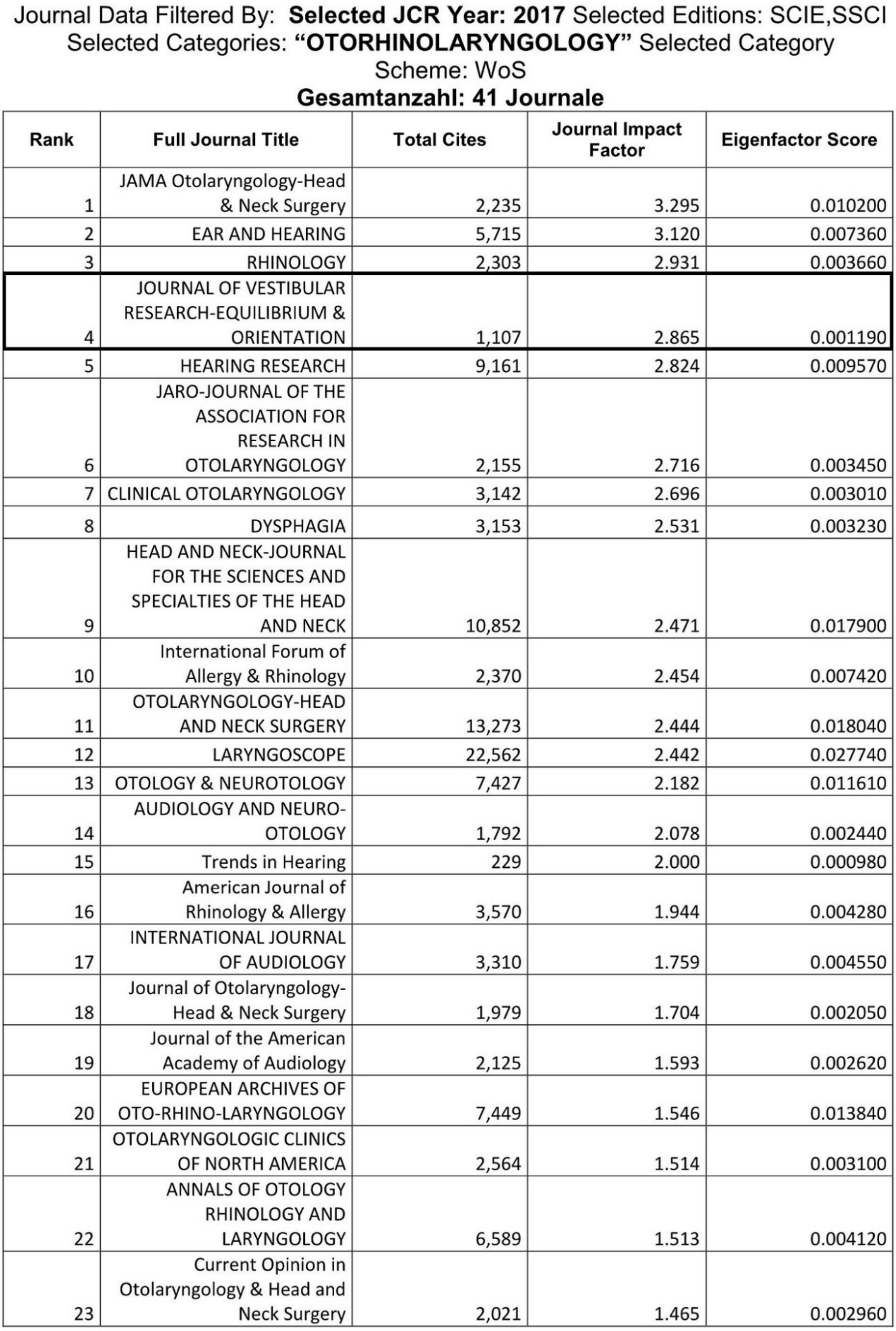
Beitrag im Einzelnen: In Zusammenarbeit mit Priv.-Doz. Dr. rer. nat. Dietmar Basta und Prof. Dr. med. Arne Ernst entwarf ich, Kristina Anton, das Studiendesign und den Versuchsaufbau. Dies inkludierte die Entwicklung der Fragestellung, die Festlegung der Ein- und Ausschlusskriterien für die Probanden, die Zusammenstellung der Voruntersuchungen, die Bestimmung der Testbedingungen und die Auswahl der Einzeltests für die Testbatterie. Der Versuchsaufbau wurde durch mich praktisch umgesetzt. Sowohl die Probandenrekrutierung und Organisation der Termine als auch die Durchführung der gesamten Voruntersuchungen und Versuche erfolgten durch mich. In den Voruntersuchungen wurde die Hör-, Seh- und Gleichgewichtsfähigkeit mittels Tonaudiometrie, Landolt-Sehtest, Standard-Balance-Defizit-Test, Messung der subjektiv haptischen Vertikalen und der zervikal vestibulär evozierten myogenen Potentiale und Kopf-Impuls-Test untersucht. Potenziellen Schwindel erfasste ich anhand eines Fragebogens (Dizziness Handicap Inventory) und einer Anamnese. Zu den Versuchen gehörte Folgendes: Aufbau und Kalibrierung des Messsystems, Einweisung und Vorbereitung der Probanden und Messung der Winkelgeschwindigkeiten bei verschiedenen Gehübungen unter verschiedenen akustischen Bedingungen. Mit Hilfe verschiedener Software (u. a. MATLAB, Audacity, VLC Media Player, Microsoft Excel) verarbeitete und analysierte ich die Ergebnisse aller Messungen. Zur Verarbeitung und Analyse der Daten mussten alle Aufnahmen akustisch und visuell geprüft und die Aufnahmen der Winkelgeschwindigkeiten und Videos synchronisiert werden. Außerdem führte ich die statistischen Analysen mit der Software IBM SPSS durch und visualisierte die Daten mittels MATLAB. Die Abbildungen (Abb. 1, 2) und die Tabelle entstanden aus meinen statistischen Analysen. Mit Priv.-Doz. Dr. rer. nat. Dietmar Basta interpretierte ich die Ergebnisse. Ich verfasste die erste Version des Manuskriptes und arbeitete die gewünschten Korrekturen der Gutachter ein.

Unterschrift, Datum und Stempel des/der erstbetreuenden Hochschullehrers/in

Unterschrift des Doktoranden/der Doktorandin

Selected publications

Extract from Journal Summary List – Publication 1



Journal Data Filtered By: **Selected JCR Year: 2017** Selected Editions: SCIE,SSCI
Selected Categories: **“OTORHINOLARYNGOLOGY”** Selected Category
Scheme: WoS
Gesamtanzahl: 41 Journale

Rank	Full Journal Title	Total Cites	Journal Impact Factor	Eigenfactor Score
1	JAMA Otolaryngology-Head & Neck Surgery	2,235	3.295	0.010200
2	EAR AND HEARING	5,715	3.120	0.007360
3	RHINOLOGY	2,303	2.931	0.003660
4	JOURNAL OF VESTIBULAR RESEARCH-EQUILIBRIUM & ORIENTATION	1,107	2.865	0.001190
5	HEARING RESEARCH	9,161	2.824	0.009570
6	JARO-JOURNAL OF THE ASSOCIATION FOR RESEARCH IN OTOLARYNGOLOGY	2,155	2.716	0.003450
7	CLINICAL OTOLARYNGOLOGY	3,142	2.696	0.003010
8	DYSPHAGIA	3,153	2.531	0.003230
9	HEAD AND NECK-JOURNAL FOR THE SCIENCES AND SPECIALTIES OF THE HEAD AND NECK	10,852	2.471	0.017900
10	International Forum of Allergy & Rhinology	2,370	2.454	0.007420
11	OTOLARYNGOLOGY-HEAD AND NECK SURGERY	13,273	2.444	0.018040
12	LARYNGOSCOPE	22,562	2.442	0.027740
13	OTOLOGY & NEUROTOLOGY	7,427	2.182	0.011610
14	AUDIOLOGY AND NEURO-OTOLOGY	1,792	2.078	0.002440
15	Trends in Hearing	229	2.000	0.000980
16	American Journal of Rhinology & Allergy	3,570	1.944	0.004280
17	INTERNATIONAL JOURNAL OF AUDIOLOGY	3,310	1.759	0.004550
18	Journal of Otolaryngology-Head & Neck Surgery	1,979	1.704	0.002050
19	Journal of the American Academy of Audiology	2,125	1.593	0.002620
20	EUROPEAN ARCHIVES OF OTO-RHINO-LARYNGOLOGY	7,449	1.546	0.013840
21	OTOLARYNGOLOGIC CLINICS OF NORTH AMERICA	2,564	1.514	0.003100
22	ANNALS OF OTOLOGY RHINOLOGY AND LARYNGOLOGY	6,589	1.513	0.004120
23	Current Opinion in Otolaryngology & Head and Neck Surgery	2,021	1.465	0.002960

Printed copy – Publication 1

Anton, K., Ernst, A., & Basta, D. (2019). Auditory influence on postural control during stance tasks in different acoustic conditions. *Journal of Vestibular Research, 29*(6), 287-294. https://doi.org/10.3233/ves-190674

Extract from Journal Summary List – Publication 2

Journal Data Filtered By: **Selected JCR Year: 2018** Selected Editions: SCIE,SSCI Selected Categories: **“OTORHINOLARYNGOLOGY”** Selected Category Scheme: WoS

Gesamtanzahl: 42 Journale

Rank	Full Journal Title	Total Cites	Journal Impact Factor	Eigenfactor Score
1	JAMA Otolaryngology-Head & Neck Surgery	2,855	3.502	0.012700
2	RHINOLOGY	2,602	3.354	0.002200
3	DYSPHAGIA	3,367	3.034	0.003470
4	EAR AND HEARING	5,747	2.954	0.006800
5	HEARING RESEARCH	9,237	2.952	0.010490
6	JOURNAL OF VESTIBULAR RESEARCH-EQUILIBRIUM & ORIENTATION	1,117	2.774	0.001440
7	Trends in Hearing	442	2.768	0.001710
8	JARO-JOURNAL OF THE ASSOCIATION FOR RESEARCH IN OTOLARYNGOLOGY	2,145	2.716	0.003400
9	International Forum of Allergy & Rhinology	2,380	2.521	0.006570
10	HEAD AND NECK-JOURNAL FOR THE SCIENCES AND SPECIALTIES OF THE HEAD AND NECK	11,100	2.442	0.018120
11	CLINICAL OTOLARYNGOLOGY	3,412	2.377	0.003940
12	LARYNGOSCOPE	22,642	2.343	0.026200
13	OTOLARYNGOLOGY-HEAD AND NECK SURGERY	13,643	2.310	0.017500
14	Journal of Otolaryngology-Head & Neck Surgery	1,910	2.175	0.002330
15	OTOLOGY & NEUROTOLOGY	8,094	2.063	0.011170
16	AUDIOLOGY AND NEURO-OTOLOGY	1,825	2.053	0.002500
17	American Journal of Rhinology & Allergy	3,290	2.015	0.004050
18	INTERNATIONAL JOURNAL OF AUDIOLOGY	3,598	1.821	0.004600
19	EUROPEAN ARCHIVES OF OTO-RHINO-LARYNGOLOGY	8,038	1.750	0.015250

Printed copy – Publication 2

Anton, K., Ernst, A., & Basta, D. (2021). A static sound source can improve postural stability during walking. *Journal of Vestibular Research, 31*(3), 143-149. https://doi.org/10.3233/ves-200015

Curriculum vitae

Mein Lebenslauf wird aus datenschutzrechtlichen Gründen in der elektronischen Version meiner Arbeit nicht veröffentlicht.

Complete list of publications

Peer-reviewed original research articles

Stone, M. A., **Anton, K.**, & Moore, B. C. J. (2012). Use of high-rate envelope speech cues and their perceptually relevant dynamic range for the hearing impaired. *The Journal of the Acoustical Society of America, 132*(2), 1141–1151. https://doi.org/10.1121/1.4733543
Impact Factor: 2.003 (2012)

Anton, K., Ernst, A., & Basta, D. (2019). Auditory influence on postural control during stance tasks in different acoustic conditions. *Journal of Vestibular Research, 29*(6), 287–294. https://doi.org/10.3233/ves-190674
Impact Factor: 2.816 (2019)

Ernst, A., **Anton, K.**, Brendel, M., & Battmer, R. D. (2019). Benefit of directional microphones for unilateral, bilateral and bimodal cochlear implant users. *Cochlear Implants International, 20*(3), 147–157. https://doi.org/10.1080/14670100.2019.1578911
Impact Factor: 1.120 (2019)

Anton, K., Ernst, A., & Basta, D. (2021). A static sound source can improve postural stability during walking. *Journal of Vestibular Research, 31*(3), 143–149. https://doi.org/10.3233/ves-200015
Impact Factor: 2.435 (2021)

Arweiler-Harbeck, D., D'heygere, V., Meyer, M., Hans, S., Waschkies, L., Lang, S., **Anton, K.**, Hessel, H., Schneider, A., Heiler, T., & Höing, B. (2021). Digital Live Imaging of Intraoperative Electrocochleography - First Description of Feasibility and Hearing Preservation During Cochlear Implantation. *Otology & Neurotology, 42*(9), 1342–1346. https://doi.org/10.1097/MAO.0000000000003256
Impact Factor: 2.311 (2021)

Conference abstracts

Anton, K., Todt, I., Ernst, A., & Basta, D. (2015). Einfluss von präoperativen, vestibulären Störungen auf das postoperative Ergebnis bei CI-Patienten. *86. Jahresversammlung der Deutschen Gesellschaft für Hals-Nasen-Ohren-Heilkunde, Kopf- und Hals-Chirurgie e.V.*, Berlin, Deutschland. (poster)

Anton, K., Battmer, R. D., Brendel, M., & Ernst, A. (2016). Benefit of Directional Microphones on Speech Perception in Noise of Cochlear Implant Users. *14th International Conference on Cochlear Implants and Other Implantable Technologies,* Toronto, Canada. (poster)

Anton, K., Ernst, A., & Basta, D. (2017). Einfluss des akustischen Inputs auf die posturale Kontrolle bei Gang- und Standkonditionen – Eine Pilotstudie –. *88. Jahresversammlung der Deutschen Gesellschaft für Hals-Nasen-Ohren-Heilkunde, Kopf- und Hals-Chirurgie e. V.,* Erfurt, Germany. (poster)

Anton, K., Battmer, R. D., Brendel, M., & Ernst, A. (2017). Benefit of Directional Microphones on Speech Perception in Noise of Unilateral and Bimodal Cochlear Implant Users. *13th European Symposium on Pediatric Cochlear Implant,* Lisbon, Portugal. (poster)

Anton, K., Battmer, R. D., Brendel, M., & Ernst, A. (2017). Benefit of Directional Microphones on Speech Perception in Noise of Unilateral and Bimodal Cochlear Implant Users. *15th Symposium on Cochlear Implants in Children*, San Francisco, USA. (poster)

Anton, K., Battmer, R. D., Brendel, M., & Ernst, A. (2017). Verbesserung des Sprachverstehens im Störgeräusch durch Richtmikrofone bei Cochlea-Implantat-Trägern. *20. Jahrestagung der Deutschen Gesellschaft für Audiologie,* Aalen, Germany. (oral presentation)

Arweiler-Harbeck, D., D'heygere, V., Meyer, M. F., Hans, S., Waschkies, L., **Anton, K.**, Heiler, T., & Höing, B. (2021). Digitale mikroskopische Echtzeit-Visualisierung der Elektrocochleographie bei Cochlea-Implantation. 92. & 91. *Jahresversammlung der Deutschen Gesellschaft für Hals-Nasen-Ohren-Heilkunde, Kopf- und Hals-Chirurgie e.V.*, Bonn, Germany. (poster)

Acknowledgements

During my doctorate, I have received valuable support from several wonderful people over the past few years. It was an exciting and challenging time in which I learned a lot and was able to broaden my scientific understanding.

Firstly, I would like to thank Prof. Dr. med. Arne Ernst and Priv.-Doz. Dr. rer. nat. Dietmar Basta for giving me the opportunity of pursuing my Ph.D. in their department. My supervisor, Priv.-Doz. Dr. rer. nat. Dietmar Basta, helped me to keep going and stood on my side whenever I had questions or challenges during my doctorate.

Another gratitude goes to my colleagues in Haus 49. They have supported my research, especially when testing the elaborate experimental setup. Without all the volunteers who participated in my experiments, the data collection for my Ph.D. would not have been possible. I really appreciate their willingness, effort and time.

I am grateful to my colleagues at Cochlear$^{\mathrm{TM}}$ for their comprehension and sympathetic ears. I especially would like to thank Dr. rer. nat. Horst Hessel for his valuable professional input to my dissertation. Without naming my friends individually, you always motivate me and have encouraging words in tough times. Last but not least, I heartfelt thank my parents and my brother. You always support me when I go my way.