Background

Hearing loss (HL) in older adults is manifested in reduced sensitivity to high frequency sounds, difficulties in distinguishing words during conversation in noisy environments, difficulties in locating sources of sounds, and in slower processing of acoustic information. HL may be caused by accumulation of age-related organ degeneration, although lifestyle (noise exposure), genetic predisposition and disease also may play important roles. Organ changes associated with HL include loss of cochlear function (for example lower endolymphatic potentiality and fewer hair cells), and cortical changes. HL is widespread among older adults: Approximately 30 percent of men and 20 percent of women over 70 in Europe have a hearing loss of 30 dB (The World Health Organization categorizes a hearing threshold of 41 dB as disabling). Consequences of HL include withdrawal from contexts where hearing is important, such as parties and social gatherings, and isolation (1, 2).

Emerging evidence suggests that HL in older adults also have an impact on balance and mobility: Lin and Ferrucci (3) found that for every 10 dB decrease in hearing, there was a 40 percent higher risk of a self-reported fall in a cohort of older people. Similarly, Viljanen and co-authors (4) found that the quartile with poorest hearing in a cohort of female twins had significantly higher odds of sustaining a fall in the year that followed, and in a longitudinal study from USA, moderate and higher hearing loss was associated with falls and incident frailty (5). Walking speed has also been found to be reduced in older adults with HL (6), and in a systematic review from 2017 (7), an independent relationship between hearing loss, and balance and mobility in older adults was found. The authors suggest several links between HL, and balance and mobility; that the association may be due to concomitant pathology in the auditory and postural control systems, that difficulties in hearing induces attentional and cognitive strain that impedes postural control, or that the association is due to behavioral factors, such as withdrawal. They conclude that further investigations are needed to shed light on the mechanisms involving HL and postural control. Further, it is suggested that some aspects of balance problems may be mitigated by hearing aids: Subjects with HL had lower Romberg times (8) or swayed more while standing still, measured on a force platform, when not wearing a hearing aid (9). Further, it appears that many older adults have difficulties with their hearing aids, or even do not use them (10), and many report hearing difficulties even when wearing them (11). The role of hearing aid use for balance warrants further investigation.

Older persons with HL have to rely more on other senses, such as vision and somatosensation. Movements and postures that are normally automatic may require conscious and executive control, mobilizing and possibly straining the musculoskeletal system. By improving postural control, older adults with HL may free bodily resources for attention and presence (12, 13). Balance exercise programs have been found to be efficacious for several balance outcomes in older adults in general (14), but we have not found studies investigating efficacy in older adults with HL. Balance and postural control can be improved by different exercise modalities:

Vestibular rehabilitation is a concept of exercises that were designed to reduce dizziness and improve balance in persons with vestibular disorders (15). Exposure to a dizziness provoking stimulus is at the core of the intervention brought on by self-initiated exercises and based on principles of habituation and adaptation/substitution. In addition, there is particular focus on balance retraining to reduce the perception of unsteadiness. Vestibular disease is a frequent comorbidity in
elderly population (16). Principles from vestibular rehabilitation therapy, may be suited for elderly persons since both dizziness and reduced balance and postural control are frequently reported in this group.

Exercises with emphasis on presence, focus and attention, with relevance to daily-life activities may be beneficial to individuals who are straining to Basic Body-Awareness Therapy (BBAT) is a physiotherapeutic approach to facilitating movement awareness. The approach is person-centered, with the aim of promoting health, learning and coping. The goal is for the patients to gain insight and knowledge of how potentials for movement can be optimized for daily life. In treatment, focus changes between facilitating more functional movement patterns and reflections (17).

As strain due to excessive cognitive load may be a link between balance and HL, an effective balance training program should likely include integrated motor and cognitive tasks. There is limited evidence regarding motor-cognitive exercise programs in older adults, but a systematic review from 2011 suggest that this type of training program shows promise for improving physical functioning in older adults (18). Such programs may for example be delivered through exergaming, which involves the user interacting with a computer, solving tasks or performing specific movements. In a 2016 study, older adults walked on a treadmill in a screen-delivered virtual reality environment (Kinetic™), avoiding obstacles and other tasks. Compared to only treadmill walking, the virtual reality group experienced fewer falls after the training. The authors point to the merging of cognitive and motor tasks as key to the relative success of the training program (19). Such exercise programs have been found to be both acceptable and enjoyable to older adults (20). Also, VR training increases intensity of the exercises, as users tend to become engaged by them (21).

The overall aim is therefore to explore the link between HL, balance and mobility in older adults. Research gaps include lack of information about both men and women, and the use of observational tests of balance and mobility as opposed to self-reported falls, which is prone to recall bias. Also, the role of hearing aids in controlling balance should be studied more extensively, using tests of movement and balance that are relevant to daily life. Further, in this study, we aim to undertake the preliminary steps of a trial of balance exercises in older adults with HL. To do so, we will conduct a feasibility/proof-of-concept trial with a limited amount of participants to investigate whether balance training has any merit in this population, and whether a large-scale trial could be carried out in terms of safety, patient recruitment and logistics.

**Methods**

This study includes three research questions:

1. **Is there an association between HL, balance and mobility in a sample of older adults?**
   To answer this question, we aim to use cross-sectional data from the ongoing fourth wave of the North-Trøndelag Health Survey (HUNT4), specifically the sub-study with extended testing of participants older than 70 years (the 70+-study). These participants will be subject to tests of balance and mobility, such as the Short Physical Performance Battery (SPPB), as well as other tests that are relevant for the older population. A substantial number of these participants will
also undergo audiometric evaluation. This enables us to explore the association between HL, balance and mobility, while controlling for other factors that may be important.

2. **Is balance in older adults with HI different than in persons with normal hearing, and does using a hearing aid change balance performance?**

   For this study, we will recruit patients with HI that are older than 70 years from general practice and hospital clinics. Participants will be invited to undergo testing at the rehabilitation lab at SimArena at Western Norway University of Applied Sciences (Høgskulen på Vestlandet; HVL). Tests will be performed with and without hearing aids, and will include tests of standing balance, walking balance and clinical balance tests. For further comparison, a group of older adults without hearing impairment will be included. We aim to include 100 older adults with HI, and 100 age- and gender matched persons without hearing problems. Additional conditions that may affect movement and balance, such as vestibular dizziness, musculoskeletal disorders and neurological disorders will be mapped to investigate the independent role of HI. Tests of balance will include standing balance (posturography) and walking balance (gait variability) (22) under both basic conditions and conditions that challenge balance (such as standing with eyes closed or walking while counting backwards). Further, clinical balance tests such as the mini-BESTest (23) will be used, for transference to clinical settings. In addition, we aim to investigate free-living behavior using body-worn sensors over several days, to ascertain movement patterns in a non-lab setting (24, 25).

3. **Is a balance training program for older adults with hearing loss feasible?**

   Participants will be recruited from the lab study. The aim is to prepare for a large scale, fully-powered trial, and results from this study will be helpful in evaluating logistics, recruitment processes and effect sizes, which can be used to determine sample size. We plan to randomize to three arms: i) vestibular rehabilitation, ii) BBAT and iii) non-immersive virtual reality walking, with 20 participants in each arm. The vestibular rehabilitation and BBAT will be delivered as groups, while the virtual reality exercises will be delivered individually. All testing and training will take place at HVL. The virtual reality program will be developed in collaboration with the masters program in ICT-engineering at HVL. The study will be process evaluated, and results will be investigated both quantitatively and qualitatively, through interviews (26). The Mini-BESTest is intended to be the primary outcome, as this test covers a wide range of balance dysfunctions.
Structure of the project

This study is intended as a PhD-project: The subject (HL, balance and mobility in older adults) is studied from different angles, and enough data will be produced to produce a comprehensive dissertation on the topic. At the same time, the project is manageable within the timeframe of a PhD-scholarship. The project should fit well within the frame of the PhD-program for health professions at HVL, with its emphasis on activity and participation.

Further, the laboratory infrastructure of SimArena (HVL) is well suited for the purposes of this study. The rehabilitation laboratory is equipped with treadmill, screens and advanced equipment for assessing balance during standing and walking. The rehabilitation lab staff is also currently involved in several projects using VR.

The proposed timeframe of the study is described below:
**Study 1:** Is there an association between HL, balance and mobility in a sample of older adults?

2018 – fall  
Dotted line: Start of PhD-period  
2019 – spring  
2019 – fall

**Study 2:** Is balance in older adults with HI different than in normal hearing, and does using a hearing aid change balance performance?

2020 – spring  
Analysis of HUNT4/70+-data  
2020 – fall  
Manuscript preparation of HUNT4/70+-data

**Study 3:** Is a balance training program for older adults with hearing loss feasible?

2018 – fall  
Developement of testing procedures  
2019 – spring  
Inclusion and testing of participants for lab-study with hearing aids  
2019 – fall

Developement of software for VR-environment

2020 – spring  
Data analysis and preparation of manuscript for lab study  
2020 – fall

Feasibility of exercise programs

2021 – spring  
Analysis of data and preparation of manuscript for feasibility study  
2021 – fall

2022 - spring  
Writing of thesis

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**Research environment:**

The project springs from the Movement and Function research group at HVL. The group is led by Professor Liv Heide Magnussen, who has long and extensive experience in rehabilitation research, with previous publications using both qualitative and quantitative designs. Professor Magnussen is the leader of the project and will be the main supervisor for the PhD-candidate.

With the internal and external partners, the research team has in depth knowledge and experience in vestibular rehabilitation, use of virtual reality applications, lab testing of older populations, hearing impairment, neurology, geriatrics and geriatric rehabilitation, and in statistics and epidemiology. We have strived to involve international partners with relevant expertise, as we believe that the addition of experiences from the global research arena will be an important stimulus to our project.

User representation is vital to the success of this project. We aim to include two user representatives from the target population (older adults with HI), as well as two physiotherapists involved in running exercise programs for older adults. Involvement from the user representatives is needed both in planning of the details of the project, in the execution of the project, in interpretation of results and in dissemination. User representatives will be recruited and appointed by the Norwegian Association for the hard of hearing.

**Internal partners (HVL):**

*Liv H Magnussen: Physiotherapist, PhD, professor (project leader, main supervisor)*
*Kjersti Wilhelmsen: Physiotherapist, PhD, associate professor*
*Tove Dragesund: Physiotherapist, PhD, associate professor*
*Bård Bogen: Physiotherapist, MSc, associate professor*
*Lars Peder Vatshelle Bovim: Physiotherapist, MSc-student, lab technician*
*Roy Miodini-Nilsen: Statistician, PhD*
*Maria Nordheim Alme: Physiologist, PhD*
External partners from Norway:
Mona Kristin Aaslund: Physiotherapist, PhD, associate professor (Haukeland University Hospital and University of Bergen).
Stein Helge Glad Nordahl: Otolaryngologist, PhD, professor (Haukeland University Hospital and University of Bergen).
Bo Engdahl: Research director, PhD (Norwegian Institute of Public Health)
Pernille Thingstad: Researcher, PhD (Norwegian University of Science and Technology)
Susanne Herms: Geriatrician, PhD, associate professor (University of Bergen).
Anette Hylen Ranhoff: Geriatrician, Dr. med, professor (University of Bergen).
Ole Martin Steihaug: Physician, PhD-student (Haukeland University Hospital).

External international partners:
Dara Meldrum: Physiotherapist, PhD, research fellow, (Trinity College, Dublin, Ireland)
Adam Goode: Physiotherapist, PhD, associate professor (Duke University, USA)
Richard Clendaniel: Physiotherapist, PhD, assistant professor (Duke University, USA)

Relevance:

Due to increased longevity and the large cohort born after the second world war, the number of citizens older than 70 in Norway is expected to double in the next 30 years. It is increasingly important that older adults are able to keep their independence in their daily lives. The ability to get around unassisted, and yet to keep from falling is vital to the quality of life in older adults. This will also reduce societal costs associated with the health care burden of an aging population. Efforts that can be made to maintain independence and mobility should therefore be explored.

Therefore, in this study, the outcomes of interest are balance and mobility. We put emphasis on these aspects of physical functioning because they are highly relevant to older adults. Unlike other physical performance outcomes, such as for example muscle strength, reduced balance and mobility is a serious hindrance to moving around freely. Being able walk, both inside one’s own home but also outside in more complex surroundings, is highly important for completing daily tasks, but also for recreation, exercise and for engaging in social relations.

HI is only one of many risk factors for falls and reduced mobility, but at the same time one that has not been studied extensively. There is also reason to believe that HI is not always taken into consideration when assessing older adults for fall risk and mobility problems. HI is potentially modifiable through the use of hearing aids, although there seems to be many who refrains from using them (27). Hearing impairment is widespread among older adults, and is frequently seen as simply a more or less inevitable part of the aging process. Findings from this study may put emphasis on hearing assessments in clinical settings.

Findings from this study will be relevant for specialized health care, but perhaps to even greater extent for primary health care. Increased awareness of HI-related balance problems is important in all levels of health care, but exercise programs are normally run in primary care settings. We also aim for a thorough dissemination of results, where findings are communicated both in scientific settings, such as conferences and in peer-reviewed journals, but also in clinical settings. This can be achieved through courses, classes and presentations. Findings will be integrated in the bachelor- and master programs in physiotherapy at our university. In collaboration with the Center for New Media at HVL, we wish to
develop and distribute digital learning resources through social media channels, that will raise both 
competence and awareness.

The exercise study is a feasibility study, to explore whether and how a larger, fully powered trial can 
be carried out in practice. Thus, special exercise groups for older adults with HI may not be the 
recommendation from this study. However, the results of a larger trial may show that the participants 
respond well to the exercises in form of improved balance. This would merit that older adults with HI 
are considered for physical activity and exercise groups.

Welfare technology is an expanding field that is greeted with optimism from stakeholders and policy 
makers. The promise of welfare technology is that needs for care and rehabilitation can be met cost-
efficiently in a health care panorama with increasingly limited resources. Thorough evaluation of 
rehabilitation methods utilizing technology, such as virtual reality, is therefore needed.

At the same time, it is important that the findings from the study are applicable in real-world settings. In 
this project, we describe the use of VR-technology but it is important to note that the Kinect™
equipment is widely commercially available at relatively low costs. Many rehabilitation and 
physiotherapy clinics have treadmills, and as such, implementation of eventual positive findings into 
clinical practice should be reasonable.

Finally, the project is multidisciplinary, drawing on knowledge and experience from several different 
fields. This mirrors real-life health care, which is of particular importance in the management of 
complex health and function issues for older adults. Further, we aim to involve students at our 
university for testing and exercising. Students included will be at both bachelor and masters level, from 
the physiotherapy, occupational therapy, sports and public health programs. This will add to the 
multidisciplinary aspect.

In summary, we have described a project that will shed light on a health problem that affect many 
older adults, have potentially serious ramifications, and is potentially remediable by physiotherapy 
interventions. We believe that the project is well suited as a PhD-project and that it should fit well 
within the PhD-program at HVL. The research team has a mix of relevant qualifications that will enable 
us to address the research questions in a scientifically sound manner. Further, we aim to utilize the 
relevant resources available at HVL, including laboratory facilities and students who are willing to 
participate.

7. Agmon M, Lavie L, Doumas M. The Association between Hearing Loss, Postural Control, and 