JAMA Otolaryngol: Head Neck Surg 147.11 (2021): 951-958

DOI: https://doi.org/10.1001/jamaoto.2021.2399

Association between hearing loss and impaired physical function, frailty and disability in older adults. A cross-sectional study

Subtitle: Hearing loss and physical function, frailty, and disability

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Date of the revision: July, 23, 2021

Manuscript word count: 3426

Key points

Question: Is hearing loss associated with impaired physical function, frailty and disability in older adults?

Findings: In this cross-sectional study of 1644 older adults, hearing loss at speech frequency PTA (0.5, 1, 2, 4 kHz) was strongly associated with impaired physical function, frailty and disability, independently of lifestyles, comorbidities, cognitive status and social isolation. The results were similar for hearing loss at standard frequency PTA (0.5, 1, 2 kHz).

Meaning: These results contribute to better characterize the nature of this association.

Abstract

Importance: Several studies have examined the association between hearing loss and physical function, with inconsistent results. Few of them used pure-tone thresholds and considered the impact of important confounders in the association.

Objective: To examine the association between hearing loss and impaired lower extremity function, frailty syndrome and disability in older adults.

Design: Cross-sectional study with 1644 community-dwelling individuals aged 65 years and older (range 66 to 91 years).

Setting: The Seniors-ENRICA-2 is a cohort study that was established in 2015-2017 in Spain.

Participants: Older adults of both genders with hearing threshold measurements and data on impaired lower extremity function, frailty syndrome and disability.

Exposures: Hearing loss defined as pure tone-average (PTA) >40 dB-HL in the better ear for standard frequency (0.5, 1, 2 kHz), speech frequency (0.5, 1, 2, 4 kHz) and high-frequency (3, 4, 8 kHz).

Main outcome and measure: Impaired lower extremity function was defined with the Short Physical Performance Battery; the frailty syndrome was defined with five criteria including weakness, slow walking speed, low physical activity, exhaustion, and weight loss; and disability in instrumental activities of daily living (IADL) was evaluated with the Lawton and Brody scale.

Results: The prevalence of hearing loss was 13.6%. After adjustment for age, gender, lifestyle, comorbidities, impaired cognition, and social isolation, hearing loss in standard frequency was associated with impaired lower extremity function, with an odds ratio (95% confidence interval) of 2.20 (1.25-3.88); the corresponding estimate for the frailty syndrome was 1.85 (0.98-3.49); and for IADL disability was 2.25 (1.29-3.94). When considering speech frequency PTA, hearing loss was also associated with impaired function: 2.59 (1.57-4.28); for frailty syndrome: 1.85 (1.06-3.22); and for IADL disability: 2.18 (1.32-3.60).

Conclusions and relevance: Hearing loss was associated with impaired lower extremity function, frailty syndrome and IADL disability. This association should be replicated and its mechanisms elucidated in further studies.

Keywords: hearing loss, physical function, frailty syndrome, aging, instrumental activities of daily living.

INTRODUCTION

Increased life expectancy has been accompanied by a heavy burden of late-life morbidity. Aging is associated with a greater prevalence of impaired sensory, motor and cognitive function, which lowers quality of life and increases dependency at this stage of life.[1] One of the most prevalent sensory impairments in the older population is hearing loss,[2] which is the fifth leading cause of disability worldwide,[3] and entails high economic costs for the society.[4] Hearing difficulties in older adults are undertreated, a situation that results in several adverse consequences, such as increased risk of depression[5] and lower quality of life.[6]

The association between hearing loss on physical function limitation, frailty and disability is unclear. Some chronic diseases, including hypertension, type 2 diabetes and cardiovascular disease have been associated with hearing loss[7-9] and are also related to disability.[10,11] In addition, sensorineural hearing loss is closely related to impaired cognition, and probably shares several age-related degenerative alterations,[12] so that cognitive impairment may lead to physical function limitation.[13] Hearing loss in the older adults may also restrict social participation, which is a determinant of disability.[14] In fact, hearing impairment might be an early physiological marker of physical function limitation.[15]

Previous studies have examined the association between hearing loss and physical function, frailty syndrome and disability with inconsistent results.[16-24] Research to better characterize hearing capacity in relation to functional capacity is needed, as well as to better understand the role of comorbidities, cognitive impairment, and social isolation in this relation. Therefore, our objective was to examine the association between hearing loss, using pure-tone average of air conduction hearing thresholds in a wide frequency range, in association with impaired lower-extremity function, frailty and disability, in a well-characterized population of older adults.

METHODS

Study design and participants

We analyzed data from the Seniors-ENRICA-2 study, a cohort study of 3273 community-dwelling individuals aged 65 years and older. Study participants were residents of the city of Madrid and four large surrounding cities holding a national health card. Participants were recruited in 2015-2017, using a random sampling stratified by gender and district. In 2019, a new data collection was conducted, updating baseline information and adding new measures, including the assessment of hearing function.

At the baseline and follow-up, data were collected in three stages, (a) telephone interview for lifestyles, morbidity, health status, use of health care information; (b) a first home visit to perform a physical examination, including an audiogram, and collect blood and urine samples; and (c) a second home visit to collect information on habitual diet and place an accelerometer in the wrist of the participants. The procedures, instruments and questionnaires were like those used in the Seniors-ENRICA I cohort.[25] In particular, for the performance of the audiograms, interviewers were provided with a specific protocol for an optimal realization, and training sessions were programmed. All study participants provided written informed consent, and the Clinical Research Ethics Committee of 'La Paz' University Hospital in Madrid approved the study.

A total of 1894 participants provided data in 2019. We selected those who had a hearing assessment that followed the specified protocol and information for the covariates of interest, so that analyses were performed with 1644 persons. Participants who rejected to perform the audiology were older, with more comorbidity, and with more prevalence of social isolation than participants who accepted to be examined.

Hearing assessment

Hearing was assessed by measuring air conduction thresholds using a hearing test at frequencies 0.5, 1, 2, 3, 4 and 8 kilohertz (kHz) in both ears. The hearing test was performed with AudCal, an application for iPhone and iPad. The evaluation was carried out in a quiet environment, face to face with the evaluator, with the mobile screen made only visible for the evaluator. The headphones used were wired in-ear headphones, distributed in iPhone packages (Earpods®). The earbuds were fitted under the standard headphones. We began evaluating the frequency 1 kHz at 0 dB-HL, increasing the sound in 5 dB-HL intervals until the participant started hearing the stimulus. After the hearing threshold was identified at that frequency, the other frequencies were completed for that ear. The same procedure was carried out for the other ear. This application has been shown high sensitivity and specificity in both ears with respect to the gold standard test, tonal audiometry in a soundproof booth, and has shown a high intra-class correlation (r = 0.93) with the standard evaluation, using an ISO-standard audiometer and standard headphones in the Spanish population.[26]

To determine hearing capacity in our study population, we calculated three pure-tone averages (PTAs) according to different frequency ranges: the first one by using the standard PTA definition (0.5, 1 and 2 kHz); the second one considering the speech frequency (0.5, 1, 2 and 4 kHz); and the third one considering the high-frequency (3, 4 and 8 kHz). We defined hearing loss in relation to three cut-off points, according to the American Speech-Language-Hearing Association: >15 dB-HL, indicating slight to profound hearing loss; >25 dB-HL reflecting mild to profound hearing loss; and >40 dB-HL, which indicates moderate to profound hearing loss.[27] We considered the hearing threshold of the better ear, following the World Health Organization (WHO) recommendations.[28]

Physical function, frailty syndrome and disability

Physical function was measured using the Short Physical Performance Battery (SPPB), which assesses gait speed, the degree of ability to get up from a chair, and balance assessment. Gait speed was calculated as the shortest time, in seconds (s), to complete two times a walking distance of 2.44 meters at a normal pace. The ability to rise from a chair was evaluated by asking the participants to stand up and sit down five consecutive times without using their hands. For the standing balance test, participants were asked to stand in three progressively challenging positions. Each component was scored on a four-point scale, and the total SPPB score was calculated by the sum of the components, ranging from 0 (worst) to 12 (best performance). Impaired lower extremity function was defined as a total score ≤6 points.[29]

The frailty syndrome was assessed according to the Fried criteria,[30] which defines frailty as the presence of at least three of the following criteria: 1) unintentional weight loss of ≥4.5 kg in the preceding year; 2) exhaustion, based on an affirmative response to any of the following questions from the Centre for Epidemiologic Studies Depression Scale: 'I felt that anything I did was a big effort' or 'I felt that I could not get going' at least 3 or 4 days a week; 3) low physical activity, defined as walking ≤2.5 h/week for males and ≤2.0 h/week for females; 4) slow walking speed, defined as the lowest cohort-specific quintile of gait speed over 2.44 m, adjusted for gender and height; 5) and muscle weakness, set as the cohort-specific lowest quintile of grip strength, measured with a Jamar dynamometer in the dominant hand, adjusted for gender and body mass index. Participants were classified as frail if they met at least 3 of the criteria.

To evaluate disability in instrumental activities of daily living (IADL) we used the Lawton and Brody scale, which evaluates complex everyday functional competences, such as shopping, doing housework, using the phone, doing laundry, preparing meals, using public transportation, managing money, and taking medications.[31] Each domain was rated dichotomously (0=capable in some degree, 1=incapable). Due to the idiosyncrasy of this population, the score for men was calculated without considering the tasks housework, laundry and preparing meals, so it ranged 0-5, whereas for women, the score included all the tasks and ranged 0-8. The score was directly proportional to the degree of dependence; disability was defined when there was a need of assistance for performing two or more IADL.[32]

Other variables

We collected self-reported information on age, educational level, tobacco and alcohol consumption. For the measurement of physical activity (metabolic equivalent tasks-h/week), an ActiGraph GT9X accelerometer was used and participants were asked to use the accelerometer for seven consecutive days.[33] We calculated the body mass index (BMI) as the weight (kg) divided by the squared height (m^2) measured under standardized conditions. Diet quality was evaluated according to the adherence to the Mediterranean Diet using the Mediterranean Diet Adherence Screener (MEDAS), whose score ranges from 0 to 14, and a higher score reflects a greater adherence to this diet.[34] The hours of sleep were evaluated with the question: *Can you tell me, approximately, how long do you usually sleep?* To assess sedentary behaviors, we considered information about television viewing (h/week). Besides, we collected the number of habitual drug treatments currently used. Since the consumption of ototoxic medication was very low (<1.1% reported consumption of aspirin, acetaminophen or ibuprofen), we added these drugs to the total number. We defined hypertension as systolic blood pressure ≥140 mm Hg or diastolic blood pressure ≥90 mm Hg or being under antihypertensive medication. In addition, diabetes was defined as fasting glucose levels ≥126 mg/dL or use of antidiabetic medication.

Participants reported if they had received a physician-based diagnosis of cancer, cardiovascular diseases (heart attack, stroke, heart failure or atrial fibrillation) and musculoskeletal diseases (arthritis, osteoarthritis or hip fracture). We also evaluated the cognitive status of the participants with the Mini Mental State Examination (MMSE), in which orientation, memory, fixation, calculation and language construction were measured; impaired cognition was defined as a score <23. Lastly, we evaluated the social participation through 5 questions: 1) *How often do you see or talk on the phone with family members (other than those who live with you*)?; 2) *How often do you see or talk on the phone with friends or neighbors?*; 3) *How much time do you usually spend alone at home?*; 4) *How often do you attend church or religious services?*; and 5) *How often do you attend senior club meetings, centers or associations to which you belong?* Each response was scored between 1 and 5, then we added the score of each question and created a scale with a range from 5 to 25, with a higher score indicating greater social participation.[35] Social isolation was defined a score below the median (<17).

Statistical analysis

We assessed differences in sociodemographic characteristics, lifestyles, comorbidities, cognitive function, and social participation between the categories of hearing status. The unpaired *t*-test or Chi-square test were used to compare continuous or categorical variables, as appropriate across the categories of hearing loss. Then, we used logistic regression to examine the association of moderate to profound hearing loss, at standard PTA, speech frequency and high-frequency PTA, with impaired lower extremity function, frailty syndrome and IADL disability. The estimates of the associations were expressed as odds ratios and 95% confidence interval. We built three logistic regression models: 1) adjusted for age and gender; 2) additionally adjusted for educational level (primary or less, secondary and university), smoking status (current smoker, former smoker, never smoker), current alcohol drinker, physical activity (tertiles of METs-h/wk), BMI (tertiles of kg/m^2), MEDAS (tertiles of the score), hours of daily sleep (tertiles), time viewing television (tertiles of h/week), and number of habitual drug treatments; 3) a third model additionally adjusted for hypertension, cancer, diabetes, cardiovascular diseases, musculoskeletal diseases, impaired cognitive function, and social isolation. We also modeled the association of the continuous PTA (per 5 dB-HL increment) in association with the studied outcomes. An analysis between hearing loss and individual subscales of the SPPB was performed; the cutoff point to define difficulty to raise from a chair, slow gait, and balance impairment was a score of ≤ 3 in each scale.

As a sensitivity analysis, we replicated the analyses defining hearing loss as PTA >25 dB-HL in the better ear, in the three frequency ranges, to understand if the association varied for milder degrees of severity of hearing loss. The analyses were performed with the STATA Software (version 15.0; Stata Corp., College Station).

RESULTS

Among study participants, 49.5% were women and the mean age was 73.8 ± 4.3 years (range: 66 to 91 years). The frequency of hearing loss according to the different definitions and cut-off points is presented in **Table 1.** We observed a high frequency of slight and mild hearing loss, in the three types of frequencies. For moderate hearing loss, the prevalence at standard PTA was 9.3% for the total population, 9.9% for men and 8.6% for women; at speech frequency PTA, the percentage was 13.6% (15.2% for men and 12.1% for women); and at high-frequency PTA, 45.1% (50.4% for men and 39.7% for women).

The participants' characteristics according to hearing status are presented in **Table 2**. In comparison with participants with normal hearing, those with moderate to profound hearing loss were older, reported lower levels of physical activity, had lower adherence to the Mediterranean diet, and spent more time watching television. In addition, they were treated with more drugs, and showed a higher prevalence of diabetes, cardiovascular diseases, and impaired cognitive function.

The association of hearing loss with impaired lower extremity function, the frailty syndrome and IADL disability is shown in **Table 3**. For standard PTA, hearing loss was associated with all the three outcomes considered, in the models adjusted for age and gender. The associations were slightly modified after further adjustment for socio-demographic and lifestyle characteristics, comorbidities, impaired cognitive function and social isolation: for impaired lower extremity function, the odds ratio (95% confidence interval) was 2.20 (1.25-3.88); for the frailty syndrome: 1.85 (0.98-3.49); and for IADL disability: 2.25 (1.29-3.94). When using speech frequency PTA, hearing loss was associated with the outcomes, and the multivariable adjustment barely modified the estimates: for impaired lower extremity function: 2.59 (1.57-4.28); for the frailty syndrome: 1.85 (1.06-3.22); and for IADL disability: 2.18 (1.32-3.60). Lastly, when we used high-frequency PTA, associations were found between hearing loss and frailty and IADL disability in the less adjusted models; however, when we adjusted for additional confounders, no association was observed.

Continuous PTA in association with the outcomes showed a direct association **(etable 1)**. More specific analyses examining the association for the subscales in the SPPB showed that difficulty to raise from a chair and balance impairment were associated with hearing loss after adjustment for all confounders (**etable 2**). Finally, when we focused on mild hearing loss, the associations were similar than those found for moderate hearing loss **(etable 3)**.

DISCUSSION

In this study of community-dwelling older adults, moderate to profound hearing loss at standard and speech frequency PTA was associated with impaired lower extremity function and IADL disability, independently of socio-demographic and lifestyle characteristics, comorbidities, cognitive impairment, and social isolation. Moderate to profound hearing loss at speech frequency PTA was also associated with the frailty syndrome after adjustment for these confounders. Similar results were also found for milder hearing loss.

In this population, 79.6 to 91.1% (depending on the PTA used) of the participants had some degree of hearing loss. These figures are higher than the most recent data from the Spanish National Health Survey 2017,[36] where 34% of people 65-74 y, 49% of people 75-84 y, and 70% of people ≥85 y reported some hearing impairment. This discrepancy reflects the fact that self-reported hearing impairment may underestimate the degree of hearing loss, particularly for milder loss. On the other hand, the prevalence of moderate to profound hearing loss in our study (9.3% for standard PTA, 13.6% for speech frequency and 45.1% for high-frequency PTA) was lower than in the United States of America (USA) among people aged ≥70 years (16.5, 26.5 and 74.1%, respectively).[37] Reasons for the lower prevalence in the Spanish population are unknown.

Regarding the association between hearing loss and impaired lower extremity function, our results were consistent with those found by Bang et al.;[16] in a cross-sectional study, defining PTA at 0.5, 1, 2 and 3 kHz, they found that hearing loss (with a hearing threshold >40 dB-HL) was linked to postural instability, which is a key component of the SPPB score. Furthermore, our results are consistent with the Health, Aging and Body Composition study, a prospective cohort of 2190 participants, where moderate hearing loss was associated with lower SPPB.[37] In addition, Lin et al.[17] using data from the US National Health and Nutrition Examination Survey observed a strong association between hearing loss and higher risk of falls. In two recent papers by Martinez-Amezcua et al., with data from the Baltimore Longitudinal Study of Aging and the Atherosclerosis Risk in Communities study, both in the USA, longitudinal analyses showed that participants with hearing loss presented faster declines in physical function over time, compared with those with normal hearing.[19,20] The same authors found that gait speed and balance were independently associated with hearing impairment.[20] This result is different to our findings, where the chair stand test showed a significant association but not gait speed.

We also observed an association between hearing loss and the frailty syndrome, as did the meta-analysis by Tan et al.[21] However, although the meta-analysis included studies at low and moderate risk of bias, more than half of the studies used self-reported measures of hearing loss, which could be susceptible to recall bias. Also, only two studies used audiometric measures to determine hearing loss and none considered lifestyles, comorbidities and social isolation simultaneously in their analyses. Regarding the association between hearing loss and IADL disability, our results are consistent with the systematic review carried out by Lin et al.[23] We have extended the above results by considering the impact of comorbidities, cognitive function, and social isolation to this association.

Hearing loss in older adults can be due to multiple causes that affect the peripheral auditory system. Among the most common causes are degenerative processes associated with age.[38] For example, adults with chronic vestibular loss have shown gait deficits.[39] Vestibular function is responsible for balance, a key component of physical function. Thus, the age-related deterioration of the hair cells that participate in both, the vestibular system and auditory system may imply that hearing loss is a surrogate of vestibular dysfunction,[40] and then, the association observed in this study may not be causal. Other mechanisms include the close relation between movement and coordination with the acoustic inputs from the environment; hearing difficulty would impede an appropriate physical response.[15] The presence of comorbidities may also indicate that several underlying common mechanisms are damaged, such as the modulation of response to stress, impaired immune response, and impaired cardiometabolic function.[41] Lastly, other non-causal explanations include the social isolation related to hearing loss, which can lead to a reduction in physical activity, and a subsequent deterioration of the physical function.[15] We adjusted our analyses for the presence of comorbidity as well as for social isolation in an effort to exclude these non-causal mechanisms.

The main limitation of our study was the cross-sectional design, so we could not attribute directionality to the observed associations. In addition, although we used pure-tone audiometry to assess hearing function, which has been proposed as the optimal metric in both, clinical settings and epidemiological studies,[42] this was performed with a portable device in at-home environment. Therefore, bias related to environmental noise and interviewer performance, as well as bias related to the instrument, cannot be discarded. Moreover, the number of cases of hearing loss for standard PTA was small. Lastly, we did not measure vestibular function, and it would have been relevant to determine its impact on the study associations. On the other hand, well established measurement tools such as the SPPB and the IADL scale were used, as well as the Fried criteria to define the frailty syndrome. Also, the analyses were adjusted for main potential confounders, including comorbidity, cognitive impairment and social isolation, which suggests that hearing impairment may be a predictor of deterioration of physical function. Finally, given that participants who accepted to perform audiometry were different than those who rejected the test, the results obtained cannot be extrapolated to a general population of community-dwelling older adults.

In conclusion, hearing loss was associated with impaired lower extremity function, the frailty syndrome and IADL disability, all common conditions in older adults. Longitudinal studies are necessary to establish causal relationships between hearing loss and these outcomes.

Acknowledgments

Conflict of Interest and Funding Disclosure: the authors declare that they have no conflicts of interest.

Sources of Support: This work was supported by FIS grants 20/1040 and 19/319 (Instituto de Salud Carlos III, State Secretary of R+D+I, and FEDER/FSE).

Authors' contributions

The authors' contributions were as follows: HYB, FFC and ELG: designed the research; HYB and FFC: performed the statistical analyses; all authors: contributed to interpretation of the results; HYB, FFC and ELG: drafted the manuscript; ELG: supervised the conduct of research and had primary responsibility for final content; and all authors: reviewed the manuscript for important intellectual content, and read and approved the final manuscript.

REFERENCES

1. Partridge L, Deelen J, Slagboom PE. Facing up to the global challenges of ageing. Nature. 2018;561(7721):45-56.

2. Agrawal Y, Platz EA, Niparko JK. Prevalence of hearing loss and differences by demographic characteristics among US adults: data from the National Health and Nutrition Examination Survey, 1999-2004. Arch Intern Med. 2008 Jul 28;168(14):1522-

3. Vos T, Allen C, Arora M, et al. Global, regional, and national incidence, prevalence, and years lived with disability for 310 diseases and injuries, 1990–2015: a systematic analysis for the Global Burden of Disease Study 2015. Lancet. 2016; 388(10053):1545-602.

4. Binti Ida Umaya. Global costs of unaddressed hearing loss and cost-effectiveness of interventions: a WHO report. Universitas Nusantara PGRI Kediri. 2017.

5. Lawrence BJ, Jayakody DMP, Bennett RJ, Eikelboom RH, Gasson N, Friedland PL. Hearing loss and depression in older adults: a systematic review and meta-analysis. Gerontologist. 2020; 60(3):e137-e154.

6. Tseng Y-C, Liu SH-Y, Lou M-F, Huang G-S. Quality of life in older adults with sensory impairments: a systematic review. Qual Life Res. 2018; 27(8):1957-71.

7. Lin BM, Curhan SG, Wang M, Eavey R, Stankovic KM, Curhan GC. Hypertension, Diuretic Use, and Risk of Hearing Loss. Am J Med. 2016 Apr;129(4):416-22.

8. Kim MB, Zhang Y, Chang Y, et al. Diabetes mellitus and the incidence of hearing loss: a cohort study. Int J Epidemiol. 2017 Apr 1;46(2):717-726.

9. Wattamwar K, Qian ZJ, Otter J, et al. Association of Cardiovascular Comorbidities with Hearing Loss in the Older Old. JAMA Otolaryngol Head Neck Surg. 2018 Jul 1;144(7):623-629.

10. Buford TW. Hypertension and aging. Ageing Res Rev. 2016/02/01. 2016 Mar;26:96-111.

11. Koye DN, Shaw JE, Magliano DJ. Diabetes and disability in older Australians: The Australian Diabetes, Obesity and Lifestyle (AusDiab) study. Diabetes Res Clin Pract. 2017;126:60-7.

12. Singer L, Green M, Rowe F, Ben-Shlomo Y, Kulu H, Morrissey K. Trends in multimorbidity, complex multimorbidity and multiple functional limitations in the ageing population of England, 2002-2015. J Comorbidity. 2019 Sep 4;9:2235042X19872030-2235042X19872030.

13. Robertson DA, Savva GM, Kenny RA. Frailty and cognitive impairment--a review of the evidence and causal mechanisms. Ageing Res Rev. 2013 Sep;12(4):840-51

14. Gopinath B, Hickson L, Schneider J, et al. Hearing-impaired adults are at increased risk of experiencing emotional distress and social engagement restrictions five years later. Age Ageing. 2012 Sep 1;41(5):618–23.

15. Brenowitz WD, Wallhagen MI. Does Hearing Impairment Affect Physical Function?: Current Evidence, Potential Mechanisms, and Future Research Directions for Healthy Aging. JAMA Netw Open. 2021 Jun 1; 4(6):e2114782.

16. Bang S-H, Jeon J-M, Lee J-G, Choi J, Song J-J, Chae S-W. Association Between Hearing Loss and Postural Instability in Older Korean Adults. JAMA Otolaryngol Neck Surg. 2020 Jun 1;146(6):530-4.

17. Lin FR, Ferrucci L. Hearing loss and falls among older adults in the United States. Arch Intern Med. 2012 Feb 27;172(4):369-71.

18. Cosiano MF, Jannat-Khah D, Lin FR, Goyal P, McKee M, Sterling MR. Hearing Loss and Physical Functioning Among Adults with Heart Failure: Data from NHANES. Clin Interv Aging. 2020; May 6;15:635-43.

19. Martinez-Amezcua P, Kuo PL, Reed NS, Simonsick EM, Agrawal Y, Lin FR, Deal JA, Ferrucci L, Schrack JA. Association of hearing impairment with higher level physical functioning and walking endurance: Results from the Baltimore Longitudinal Study of Aging (BLSA). J Gerontol A Biol Sci Med Sci. 2021 May 18:glab144. doi: 10.1093/gerona/glab144. Online ahead of print.

20. Martinez-Amezcua P, Powell D, Kuo PL, Reed NS, Sullivan KJ, Palta P, Szklo M, Sharrett R, Schrack JA, Lin FR, Deal JA. Association of Age-Related Hearing Impairment With Physical Functioning Among Community-Dwelling Older Adults in the US. JAMA Netw Open. 2021 Jun 1;4(6):e2113742.

21. Tan BKJ, Man REK, Gan ATL, et al. Is Sensory Loss an Understudied Risk Factor for Frailty? A Systematic Review and Meta-analysis. J Gerontol A Biol Sci Med Sci. 2020 Nov 13;75(12):2461-2470.

22. Sardone R, Castellana F, Bortone I, et al. Association Between Central and Peripheral Age-Related Hearing Loss and Different Frailty Phenotypes in an Older Population in Southern Italy. JAMA Otolaryngol Neck Surg. 2021 Feb 11; Available from: https://doi.org/10.1001/jamaoto.2020.5334

23. Lin T-C, Yen M, Liao Y-C. Hearing loss is a risk factor of disability in older adults: A systematic review. Arch Gerontol Geriatr. 2019;85:103907.

24. Mueller-Schotte S, Zuithoff NPA, van der Schouw YT, Schuurmans MJ, Bleijenberg N. Trajectories of Limitations in Instrumental Activities of Daily Living in Frail Older Adults With Vision, Hearing, or Dual Sensory Loss. J Gerontol A Biol Sci Med Sci. 2019 May;74(6):936-42.

25. Rodríguez-Artalejo F, Graciani A, Guallar-Castillón P, et al. Rationale and methods of the study on nutrition and cardiovascular risk in Spain (ENRICA). Rev Esp Cardiol. 2011; 64(10):876-882.

26. Larrosa F, Rama-Lopez J, Benitez J, et al. Development and evaluation of an audiology app for iPhone/iPad mobile devices. Acta Otolaryngol. 2015; 135(11):1119-27.

27. Degree of Hearing Loss [Internet]. [cited 2021 Mar 2]. Available from: https://www.asha.org/public/hearing/degree-of-hearing-loss/

28. WHO Report of the Informal Working Group On Prevention Of Deafness And Hearing Impairment Programme Planning. Geneva, 1991.

29. Guralnik JM, Ferrucci L, Pieper CF, et al. Lower extremity function and subsequent disability: consistency across studies, predictive Models, and value of gait speed alone compared with the short physical performance battery. Journals Gerontol Ser A. 2000; 55(4):M221-31.

30. Fried LP, Tangen CM, Walston J, et al. Frailty in Older Adults: Evidence for a Phenotype. Journals Gerontol Ser A. 2001;56(3):M146-57.

31. Lawton MP, Brody EM. Assessment of older people: self-maintaining and instrumental activities of daily living. Gerontologist. 1969; 9(3):179-186.

32. Machado-Fragua MD, Struijk EA, Graciani A, Guallar-Castillon P, Rodríguez-Artalejo F, Lopez-Garcia E. Coffee consumption and risk of physical function impairment, frailty and disability in older adults. Eur J Nutr. 2019; 58(4):1415-27.

33. Cabanas-Sánchez V, Esteban-Cornejo I, Migueles JH, et al. Twenty four-hour activity cycle in older adults using wrist-worn accelerometers: The seniors-ENRICA-2 study. Scand J Med Sci Sport. 2020 Apr;30(4):700-708.

34. Schröder H, Fitó M, Estruch R, et al. A short screener is valid for assessing Mediterranean Diet adherence among older Spanish men and women. J Nutr. 2011; 141(6):1140-5.

35. Levasseur M, Richard L, Gauvin L, Raymond É. Inventory and analysis of definitions of social participation found in the aging literature: Proposed taxonomy of social activities. Soc Sci Med. 2010;71(12):2141-9.

36. Spanish Statistical Office [Internet]. [cited 2021 Mar 11]. Available from: https://www.ine.es/en/index.htm

37. Lin FR, Thorpe R, Gordon-Salant S, Ferrucci L. Hearing Loss Prevalence and Risk Factors Among Older Adults in the United States. Journals Gerontol Ser A. 2011 May 1;66A(5):582-90.

38. Jayakody DMP, Friedland PL, Martins RN, Sohrabi HR. Impact of Aging on the Auditory System and Related Cognitive Functions: A Narrative Review. Front Neurosci. 2018 Mar 5; 12:125.

39. Grove CR, Whitney SL, Pyle GM, Heiderscheit BC. Instrumented Gait Analysis to Identify Persistent Deficits in Gait Stability in Adults With Chronic Vestibular Loss. *JAMA Otolaryngol Head Neck Surg.* Published online July 01, 2021. doi:10.1001/jamaoto.2021.1276

40. Cunningham LL, Tucci DL. Hearing loss in adults. N Engl J Med. 2017. Dec 21;377(25):2465-2473.

41. Spankovich C., Le Prell C. G. Healthy diets, healthy hearing: National Health and Nutrition Examination Survey, 1999-2002. Int J Audiol. 2013. 52:369-76.

42. Lin FR, Reed NS. The Pure-Tone Average as a Universal Metric—Knowing Your Hearing. JAMA Otolaryngol Head Neck Surg. 2020 Dec 23. doi: 10.1001/jamaoto.2020.4862. Online ahead of print.

Table 1. Prevalence of hearing loss in the participants according to the definitions of hearing loss, by gender.[1,2] N=1644

	All Participants			Men			Women		
	>15 dB-HL[3]	>25 dB-HL[4]	>40 dB-HL[5]	>15 dB-HL [3]	>25 dB-HL [4]	>40 dB-HL [5]	>15 dB-HL [3]	>25 dB-HL [4]	>40 dB-HL [5]
Standard PTA $_{0.5, 1, 2\ kHz}$, n (%)	1308 (79.6)	659 (40.1)	152 (9.3)	658 (79.2)	333 (40.1)	82 (9.9)	650 (80.0)	326 (40.1)	70 (8.6)
Speech frequency PTA $_{0.5, 1, 2, 4\ kHz}$, n (%)	1388 (84.4)	866 (52.7)	224 (13.6)	715 (86.0)	465 (56.0)	126 (15.2)	673 (82.8)	401 (49.3)	98 (12.1)
High-frequency PTA $_{3, 4, 8\ kHz}$, n (%)	1498 (91.1)	1259 (76.6)	742 (45.1)	768 (92.4)	668 (80.4)	419 (50.4)	730 (90.0)	591 (72.7)	323 (39.7)

PTA: pure total average.

[1]Hearing loss in the better ear of the participants.

[2]The prevalence values are represented as number of cases and percentage in each definition of hearing loss.

[3] Definition from slight to profound hearing loss.

[4] Definition from mild to profound hearing loss.

[5] Definition from moderate to profound hearing loss.

Table 2. Participants' characteristics, at different frequency ranges (N=1644)[1,2,3]

	Hearing status					
	Standard PTA $_{0.5,1,2\ kHz}$		Speech frequency PTA $_{0.5,1,2,4\ kHz}$		High-frequency PTA $_{3,4,8\ kHz}$	
	Normal	Hearing loss	Normal	Hearing loss	Normal	Hearing loss
N	1,492	152	1,420	224	902	742
Age, y	73.5±4.2	76.8±4.8[c]	73.4±4.1	76.4±4.8[c]	72.7±3.9	75.1±4.5[c]
Educational level; primary or less, %	58.9	65.1	59.1	61.6	57.8	61.5
Current smoker, %	8.9	5.3	9.1	4.5	9.0	7.8
Current alcohol drinker, %	33.4	29.6	33.0	33.0	32.9	33.2
Physical activity, MET-h/week	23.7±8.9	21.1±9.7[c]	23.9±8.8	20.2±9.4[c]	24.6±8.7	22.0±9.1[c]
Body mass index, kg/m^2	27.6±4.4	28.1±4.9	27.6±4.4	28.1±4.8	27.5±4.5	27.8±4.4
Adherence to the MEDAS score	7.3±1.7	6.9±1.7[a]	7.3±1.7	6.9±1.6[c]	7.3±1.7	7.2±1.6
Hours of daily sleep	6.7±1.3	6.6±1.5	6.7±1.3	6.7±1.5	6.7±1.2	6.7±1.4
Television viewing, h/week	24.6±12.8	28.4±14.7[c]	24.5±12.7	27.7±14.8[c]	24.3±12.6	25.7±13.6[a]
Number of habitual drugs	4.1±3.0	5.1±3.3[c]	4.0±3.0	5.1±3.2[c]	3.7±2.9	4.7±3.1[a]
Chronic diseases,						
Hypertension, %	68.2	71.7	68.2	70.5	66.1	71.6[a]
Diabetes, %	22.7	32.2[b]	22.1	32.6[b]	20.5	27.2[b]
Cancer, %	10.7	12.5	10.8	11.6	10.8	11.1
Cardiovascular diseases*, %	7.3	7.9	6.8	10.7[a]	6.2	8.8[a]
Musculoskeletal diseases**, %	48.1	50.0	48.2	49.1	48.5	48.1
Impaired cognitive function, %	2.2	5.3[a]	2.1	4.9[a]	2.1	3.0
Social isolation, %	43.4	42.1	43.7	40.6	44.0	42.5
Impaired lower extremity function (SPPB score ≤6), %	6.0	17.8[c]	5.4	17.9[c]	4.4	10.2[c]
Frailty syndrome[4], %	4.2	11.8[c]	3.9	11.2[c]	3.1	7.1[c]
IADL disability[5], %	5.8	19.1[c]	5.4	17.4[c]	4.6	10.1[c]

[1] Defined as normal (PTA ≤40 dB-HL) and as moderate to profound hearing loss (PTA >40 dB-HL) in the better ear.

[2] Abbreviations. PTA: pure-tone average; METs: metabolic equivalent tasks; MEDAS: Mediterranean Diet Adherence Screener; SPPB: Short Physical Performance Battery; IADL: Instrumental Activities of Daily Living.

[3]Values are means ±SD unless otherwise indicated. P values based on Student's *T* test, for continuous variables or chi-square test for qualitative variables.

[4]The diagnosis of the frailty syndrome was based on the Fried criteria (weakness, low speed, low physical activity, exhaustion, and weight loss).

[5] IADL disability was defined as need of assistance for performing two or more IADL.

[*] Includes heart attack, stroke, heart failure and atrial fibrillation.

[**]Includes arthritis, osteoarthritis and hip fracture.

[a]p<0.05 [b]p<0.01 [c]p<0.001

Table 3. Association between moderate to profound hearing loss and impaired lower extremity function, frailty syndrome and IADL disability. N=1644.

	Hearing loss, standard PTA $_{0.5,1,2\ kHz}$	Hearing loss, speech frequency PTA $_{0.5,1,2,4\ kHz}$	Hearing loss, high-frequency PTA $_{3,4,8\ kHz}$
	Odds ratio (95% confidence interval)	Odds ratio (95% confidence interval)	Odds ratio (95% confidence interval)
Impaired lower extremity function			
Number of cases	27	40	76
Model 1	2.14 (1.28-3.58)*	2.59 (1.64-4.09)*	1.75 (1.14-2.68)*
Model 2	2.06 (1.18-3.60)*	2.48 (1.52-4.05)*	1.47 (0.93-2.33)
Model 3	2.20 (1.25-3.88)*	2.59 (1.57-4.28)*	1.50 (0.95-2.39)
Frailty syndrome			
Number of cases	18	25	53
Model 1	2.22 (1.23-4.00)*	2.34 (1.37-3.98)*	2.00 (1.22-3.29)*
Model 2	1.90 (1.02-3.54)*	1.88 (1.09-3.26)*	1.59 (0.95-2.65)
Model 3	1.85 (0.98-3.49)*	1.85 (1.06-3.22)*	1.59 (0.95-2.67)
IADL disability			
Number of cases	29	39	75
Model 1	2.39 (1.45-3.94)*	2.41 (1.53-3.78)*	1.63 (1.07-2.49)*
Model 2	2.21 (1.30-3.78)*	2.18 (1.35-3.51)*	1.29 (0.83-2.03)
Model 3	2.25 (1.29-3.94)*	2.18 (1.32-3.60)*	1.33 (0.83-2.12)

Abbreviations: PTA: pure total average; IADL: Instrumental Activities of Daily Living.

Hearing loss defined as PTA >40 dB-HL in the better ear.

* Statistically significant at alpha = 0.05

Model 1: adjusted for age and gender.

Model 2: Additionally adjusted for educational level (primary or less, secondary and university), smoking status (current smoker, former smoker, never smoker), current alcohol drinker, physical activity (tertiles of METs-h/wk, BMI (tertiles of kg/m^2), MEDAS (tertiles of score), hours of daily sleep (tertiles), time viewing television (tertiles, h/week) and number of drugs currently used.

Model 3: Additionally adjusted for hypertension, diabetes, cancer, cardiovascular diseases, musculoskeletal diseases, impaired cognitive function and social isolation.