Hearing-aid use and long-term health outcomes: Hearing handicap, mental health, social engagement, cognitive function…

Article *in* International journal of audiology · July 2015

DOI: 10.3109/14992027.2015.1059503 · Source: PubMed

CITATIONS
2

READS
221

6 authors, including:

Piers Douglas Dawes
The University of Manchester
40 PUBLICATIONS **499** CITATIONS

SEE PROFILE

Hearing aid use and long-term health outcomes: hearing handicap, mental health, social engagement, cognitive function, physical health and mortality

Piers Dawes,[1] Karen J. Cruickshanks,[2,3] Mary E. Fischer, [3] Barbara E.K. Klein,[3] Ronald Klein[3], David M. Nondahl,[3]

[1]School of Psychological Sciences, University of Manchester, Manchester UK [2] Population Health Sciences School of Medicine and Public Health, University of Wisconsin, Madison, WI [3]Ophthalmology and Visual Sciences, School of Medicine and Public Health, University of Wisconsin, Madison, WI

Key words*:* Hearing aids, hearing impairment, activities of daily living, mental health, cognitive function, social engagement.

Correspondence:

Correspondence should be addressed to Piers Dawes, PhD, School of Psychological Sciences, University of Manchester, Oxford Road, Manchester, M13 9PL, UK. E-mail: piers.dawes@manchester.ac.uk

Abstract

Objective: To clarify the impact of hearing aids on mental health, social engagement, cognitive function, and physical health outcomes in older adults with hearing impairment. *Design:* We assessed hearing handicap (Hearing Handicap Inventory for the Elderly; HHIE-S), cognition (Mini Mental State Exam, Trail Making, Auditory Verbal Learning, Digit-Symbol Substitution, Verbal Fluency, incidence of cognitive impairment), physical health (SF-12 physical component, basic and instrumental activities of daily living, mortality), social engagement (hours per week spent in solitary activities) and mental health (SF-12 mental component) at baseline, 5 years prior to baseline, and 5 and 11 years after baseline. *Study sample:* Community-dwelling older adults with hearing impairment (N=666) from the Epidemiology of Hearing Loss Study cohort. *Results:* There were no significant differences between hearing aid users and non-users in cognitive, social engagement or mental health outcomes at any time point. Aided HHIE-S was significantly better than unaided HHIE-S. At 11 years hearing aid users had significantly better SF-12 physical health scores (46.2 versus 41.2; p=0.03). There was no difference in incidence of cognitive impairment or mortality. *Conclusion:* There was no evidence that hearing aids promote cognitive function, mental health, or social engagement. Hearing aids may reduce hearing handicap and promote better physical health.

Hearing impairment is common among older adults. In the Epidemiology of Hearing Loss Study (EHLS), 45.9% of adults aged over 48 years had hearing impairment (defined as an average threshold >25dB over 500 to 4000Hz in the worse ear; Cruickshanks et al., 1998). Hearing impairment is associated with reduced emotional, social and physical well-being (Mulrow et al., 1990; Strawbridge et al., 2000; Arlinger, 2003; Dalton et al., 2003; Chia et al., 2007; Gopinath et al., 2009). Hearing impairment also may be associated with cognitive decline and dementia (Peters et al., 1988; Ulhmann et al., 1989; Lindenberger & Baltes, 1994; Baltes & Lindenberger, 1997; Lin et al., 2004; Gallacher et al., 2012; Lin et al., 2013; Gurgel et al., 2014; Dawes et al., 2015).

The primary treatment for hearing impairment is provision of hearing aids. Research from observational studies, quasi-experimental studies and randomized controlled trials (RCTs) reviewed below provides consistent evidence that hearing aids reduce hearing handicap. There is limited and inconsistent evidence for the impact of hearing aids on a wider range of outcomes including mental health, physical health, cognitive function and social engagement.

To begin with studies that utilized an observational design, the results of a large industry-sponsored observational survey of people with hearing loss in the US (N=2069) concluded that hearing aid users had better social engagement, mental health and physical health than non-users (Kochkin & Rogin, 2000). However, hearing aid users tended to be more affluent than non-users, and this potential confounder was not accounted for in the comparison. A wide range of health- and quality of life-related factors are strongly associated with socio-economic status

(Mackenbach et al., 1997; Marmot et al., 2012), so it is difficult to know whether the apparent advantage of hearing aid users is due to hearing aid use or to socio-economic differences.

Appolonio et al (1996) surveyed quality of life and mortality in Italian adults (N=1192) with and without hearing and/or vision impairment. Appolonio et al compared three groups; i) no functional sensory impairment, ii) corrected impairment (hearing aid and/or glasses) and iii) uncorrected impairment. Sensory impairment and the effectiveness of correction were determined via binocular visual acuity testing and a free-field whispered voice test. Appolonio et al reported that uncorrected sensory impairment was associated with poorer social engagement and poorer mental health. Quality of life outcomes were similar for the groups with no sensory impairment and corrected impairment. In longitudinal analysis, uncorrected sensory impairment was associated with increased 6-year mortality in men only. A difficulty with Appolonio et al's study is that hearing impairment and hearing aid use were not reported separately from vision impairment and glasses use, so it is difficult to know what the contribution of hearing aid use was to quality of life and mortality outcomes.

In a cross-sectional analysis of data from the Baltimore Longitudinal Study of Aging, Lin et al (2011) reported that more severe hearing loss (average hearing threshold across 0.5, 1, 2, and 4 kHz in the better ear) was associated with poorer mental status (Mini-Mental State Exam), memory (Free and Cued Selective Reminding Test) and executive function (Stroop Test; Trial Making B) in regression modelling that included age, sex, ethnicity, education level, diabetes, smoking and hypertension. Among those with clinically significant levels of hearing loss

(N=142), Lin et al found that there was no difference in cognition between hearing aid users (N=46) and non-users.

Chisolm et al's (2007) systematic review of the impact of hearing aids on health-related quality of life identified 16 studies, including 14 studies that used a quasi-experimental design, with non-random allocation to experimental and control groups or no control group. The remaining two studies included in Chisolm et al's review were randomized controlled trials (mentioned in the following paragraph). Chisolm et al concluded that hearing aids were associated with small positive effects on general health-related quality of life measures (such as the SF-36 and EQ5D), with medium to large positive effects on measures of hearing disability (such as the HHIE).

In relation to randomized controlled trials (RCTs) of the impact of hearing aids, a recent review on behalf of the U.S. Preventive Services Task Force (Moyer, 2012) identified four RCT studies (Mulrow, Aguilar et al., 1990; Jerger et al., 1996; Yueh et al., 2001; Tolson et al., 2002). Three RCTs reported reductions in hearing handicap in the hearing aid group versus the control group (Mulrow, Aguilar et al., 1990; Yueh, Souza et al., 2001; Tolson, Swan et al., 2002); no significant impact of hearing aid use on hearing handicap was detected by Jerger et al (1996). Limited information is available from RCTs on the effect of hearing aids on cognitive function, social engagement, mental health and general health. Mulrow et al (1990) reported small improvements in social engagement, mental health and cognition. No improvements in mental health, social engagement or quality of life for hearing aids versus the unaided condition were reported by Jerger et al (1996).

In summary, there is converging evidence from observational, quasi-experimental and RCT studies that hearing aids reduce hearing handicap. There is limited and inconsistent evidence for the impact of hearing aids on mental health, physical health, cognitive function and social engagement. Further, all studies to date have been limited to relatively short term outcomes associated with hearing aid use. One would expect that the positive impact of hearing aid use on some outcome variables may only emerge after a longer time frame. For example, cognitive decline in older adults is gradual and only observable over a timescale of years (Salthouse, 1991). Any protective effect of hearing aid use against cognitive decline may therefore only be observable over a timescale of a few years. Practical and ethical constraints preclude RCT studies of hearing aid use with outcomes measured over several years. An alternative is to examine outcomes associated with hearing aid use in longitudinal data sets that contain outcome data of interest, while controlling statistically for any potential confounders between hearing aid users and non-users.

The aim of the present study was to determine the association of hearing aid use with a wide range of outcome measures in hearing impaired adults controlling for demographic differences between hearing aid users and non-users. Outcomes included mental health, cognitive function, incident cognitive impairment, hearing handicap, social engagement, general health, and mortality. Outcomes were modeled in the Epidemiology of Hearing Loss Study (EHLS), a longitudinal data set with outcomes assessed with 5 years and 11 years of follow-up. The hypothesis was that among hearing impaired adults, hearing aid use would be associated with better outcomes.

Method

Participants

The present study involved a subsample of the Epidemiology of Hearing Loss Study (EHLS) cohort. This cohort was described in detail elsewhere (Cruickshanks et al., 1998). Briefly, the EHLS aimed to estimate the prevalence of hearing impairment in adults aged 48-92 years living in Beaver Dam, Wisconsin. The first round of testing (pre-baseline, for the purposes of this paper) took place between 1993 and 1995 and included audiometric examination and a questionnaire on hearing-related medical history, potential risk factors for hearing impairment and self-perceived hearing handicap. Of the 4,541 people eligible to take part, 3,753 (82.6%) participated. There were 2,800 participants in the baseline examination (1998-2000), 2,395 in 5-year (2003-2005), and 1,812 in 11-year (2009-2010) examinations. A subsample of EHLS participants was included in the present study (N = 666) on the basis of having hearing impairment but no hearing aid at pre-baseline. Among those with hearing impairment 130 were excluded because they reported using hearing aids at pre-baseline. Hearing impairment was defined as having an average threshold over 3 and 4 kHz greater than 40 dB HL in the better ear. This corresponds to at least a moderate level of hearing loss affecting audiometric frequencies important for speech perception. This level of hearing loss would be expected to result in communication disability and indicates candidacy for a hearing aid, according to the WHO definition of disabling hearing loss as hearing loss greater than 40dB in the better ear in adults (http://www.who.int/mediacentre/factsheets/fs300/en/). Participants were further grouped according to either having obtained hearing aids by the time of the baseline examination and who reported using hearing aids at least some of the time at baseline (HA user, N = 69) or not (Non-user, N = 597).

Measurements

Measures at each time point are shown in table 2 and are described as follows. Note that not all measures were completed at every time point.

Hearing handicap. Participants completed the Hearing Handicap Inventory for the Elderly and for Adults – Screening version (HHIE-S; Ventry & Weinstein, 1983). The HHIE-S assesses the social and emotional impact of any perceived hearing impairment. Higher scores correspond to greater perceived handicap, with scores greater than 8 suggesting clinically significant levels of handicap. The HHIE-S may be completed for either aided or unaided listening.

Cognition. Participants completed the Mini Mental State Examination (MMSE; Folstein et al., 1975), a screening test to identify cognitive impairment. Other cognitive measures included the Trail Making Test (TMT; Bowie & Harvey, 2006), the Digit Symbol Substitution Test (DSST; Wechsler, 1991), Auditory Verbal Learning Test (AVLT; Schmidt, 1996), and the Verbal Fluency Test (VFT; Strauss et al., 2006). Incident cognitive impairment was identified between baseline and 11 year follow-up if a participant scored less than 24 points on the MMSE, or Alzheimer's Disease or significant dementia was reported by the participant or by proxy report.

Physical health. Physical health was indexed by the Physical Component Score (PCS) from the SF-12 short form health survey (Ware et al., 1996). The PCS is a measure of self-perceived quality of physical health. Scores range between 0 and 100 with lower scores indicating higher levels of perceived disability. Participants also completed the Activities of Daily Living (ADL; Katz at al., 1970) and Instrumental Activities of Daily Living (IADL;

Lawton & Brody, 1969). The ADL and IADL are indexes of disability in relation to basic self-care tasks and daily activities which are not necessary for basic self-care but are required for independent living within the community, respectively. Mortality was recorded via the Wisconsin Department of Health and Family Services or the National Death Index for all known deaths as well as persons with whom we had lost contact.

Social engagement. A proxy measure of social engagement was taken as the average number of hours per week spent in solitary activities using a computer, watching TV, or reading, according to self-report.

Mental health. The Mental Component Score (MCS) from the SF-12 (Ware, Kosinski et al., 1996) was used as a measure of self-perceived quality of mental health. Scores range between 0 and 100 with lower scores indicating higher levels of perceived disability.

Statistical analyses

Demographic and hearing characteristics at pre-baseline and baseline were first compared for the new hearing aid users group (n=69) versus the non-users (n=597) without adjustment for the other covariates of age, sex and severity of hearing impairment. The chi-square test for association (for sex, education and income) or the t-test for difference in means (for age and severity of hearing impairment) was used to assess the significance of the group comparisons. Sample sizes for the chi-square tests were adequate based on expected cell sizes for the r x c categorical tables. The usual adjustment for unequal sample sizes was used for the two-sample t-tests. Hearing handicap, cognition, physical health, social engagement, and mental health outcomes at pre-baseline, baseline, and at 5 and 11 years after baseline were modeled with analysis of covariance (ANCOVA) models comparing the new hearing aid users with the non-

users categorized according to use at baseline, controlling for potential confounders age, gender and severity of hearing impairment (based on the average of the audiometric threshold across .5, 1, 2 and 4 kHz in the better ear). Any comparisons that were significant or marginally significant (p<0.10) were examined with additional potential confounders including cardiovascular disease, total cholesterol, diabetes, current alcohol consumption, history of heavy drinking, hypertension and smoking measured at baseline. Selection of potential confounders was based on associations that have been previously reported between chronic disease and lifestyle factors and hearing impairment (for a review, see Cruickshanks et al., 2010).

A Cox proportional hazard model was used to model the cumulative incidence of cognitive impairment between baseline and 11 year follow-up comparing hearing aid users with non-users, controlling for potential confounders age, sex and severity of hearing impairment. Kaplan-Meier survival estimates were calculated for the new hearing aid and the non-user groups for the time between baseline and 11 year follow-up. Risk of death during that period for the two groups was compared using Cox proportional hazards models. All analyses were performed using the SAS System (SAS Institute Inc, Gary, NC).

Results

There were no significant differences between hearing aid users and non-users in any demographic index (Table 1). Hearing aid users had a significantly greater level of hearing loss than non-users. Based on self-report measures, all users wore their hearing aids at least some of the time, 73% of hearing aid users wore their aids every day and 67% wore them more than 8 hours per day. The groups differed significantly with respect to hearing handicap (Table 2).

Hearing aid users had significantly ($p < 0.01$) higher HHIE-S scores at pre-baseline and baseline. There were no significant cognition, physical or mental health group differences at baseline (Table 2). At the 5 year follow-up, 137 of the original 666 participants had died, and 37 were unavailable for assessment. At the 11 year follow-up, a further 167 had died, with 13 participants unavailable.

(Table 1 here)

At the 5 year follow-up (Table 2), as observed at baseline, unaided HHIE-S scores were significantly higher in the hearing aid user group than in the non-user group ($p < 0.01$), but both groups had average scores slightly higher than at baseline and were within the clinical range suggesting significant hearing handicap. The mean aided HHIE-S score among the users (10.5) was very close to the mean unaided HHIE-S score among the non-users (10.8). Among hearing aid users, the aided HHIE-S score was statistically significantly lower than the unaided score (Paired t-test for difference; $p < 0.01$, Cohen's $d = 1.4$). The mean HHIE-S score among EHLS participants with normal hearing (i.e. thresholds less than 40dB HL at 3 and 4 kHz in the better ear) was 3.2, statistically significantly lower than the aided HHIE-S score among hearing aid users (adjusting for age and sex; $F(2,1221) = 62.3$, $p < 0.01$, Cohen's $d = 0.5$) (data not shown). Hearing aids appear to reduce hearing disability among those with hearing impairment, although levels of self-reported hearing disability remain higher than for those with normal hearing. There were no significant differences in cognitive, physical health, social engagement, or mental health scores between hearing aid status groups, adjusting for age, gender and average hearing loss. A

slightly higher SF-12 Physical Component Score among hearing aid users (46.0) compared to non-users (42.7) was not statistically significant ($p = 0.06$).

(Table 2 here)

At 11 years post baseline, hearing aid users reported significantly higher levels of hearing disability as measured by the unaided HHIE-S than non-users ($p < 0.01$). There were no significant differences between hearing aid users and non-users in any of the cognitive tests. By the 11 year follow-up, the rate of incident cognitive impairment was 11.1% for the hearing aid users versus 15.5% for non-users. The difference was not statistically significant ($p = 0.49$). Hearing aid users had a statistically significantly ($p = 0.03$) higher (better) mean SF-12 Physical Component Score than non-users (46.2 vs. 41.2, respectively). There were no significant differences between groups in any of the other physical or mental health measures. The significant and marginally non-significant ($p < 0.10$) comparisons were re-tested with more extensive adjustment for additional potential confounders (cardiovascular disease, total cholesterol, diabetes, current alcohol consumption, history of heavy drinking, hypertension and smoking measured at baseline). Unaided HHIE-S score remained statistically significantly poorer in hearing aid users, although there were no significant differences in the remaining measures of cognition, mental or physical health. By the end of the 11 year examination, 47.6% of non-hearing aid users had died versus 47.8% of hearing aid users. Adjusted for age, sex and severity of hearing loss, the *p*-value for comparing mortality among users and non-users was 0.18, and with further adjustment for additional covariates (cardiovascular disease, total cholesterol, diabetes, current alcohol consumption, history of heavy drinking, hypertension and smoking measured at baseline), $p = 0.16$.

All analyses were re-run excluding any non-HA users at baseline who subsequently began using a HA (n=91) and HA users who gave up using a hearing aid (n=7) between baseline and 11-year outcome assessment (Supplemental table). The results of this analysis were similar to those for the whole sample. The differences in the adjusted mean Physical Component Score between HA users and non-users were very close in the two samples (whole sample = 5.0; sub-sample = 4.6). However, because of the appreciable reduction in sample size in the sub-sample, the difference was now marginally significant ($p = 0.07$). In the sub-sample, the HA users had a significantly lower adjusted mean number of limitations on ADL than non-users (HA users = 0.2; non-users = 1.0, $p = 0.04$).

Discussion

This study modeled hearing handicap, cognitive function, physical health, social engagement, and mental health measures associated with hearing aid use in a longitudinal cohort. Participants were all identified as having hearing impairment. Participants were grouped according to whether or not a new hearing aid had been acquired in the 5 years prior to baseline and the experience of these groups with respect to the outcomes were compared at the 5 year and at the 11 year follow-up periods. Adjustment for demographic and hearing level factors was performed.

All participants reported high levels of hearing handicap. Hearing aid users tended to report higher levels of handicap, and this difference was statistically significant after controlling for differences in hearing threshold. This may be because the recognition of hearing difficulties is a major determinant of hearing aid uptake (Vestergaard Knudsen et al., 2010), or may be due to insufficient control for differences in hearing impairment. For hearing aid users, self-reported hearing handicap was significantly lower for aided than unaided listening. However, aided scores

still suggested clinically significant levels of hearing handicap. Aided scores were statistically significantly higher than the unaided scores of those with no hearing impairment and not significantly different from the unaided scores of those with hearing impairment but no hearing aid. Our interpretation is that hearing aids were associated with reduced handicap, but that hearing aid users were still likely to experience significant levels of handicap. This is consistent with research that suggests that hearing aids reduce hearing handicap (Mulrow et al., 1990; Tesch-Römer, 1997; Yueh, Souza et al., 2001; Tolson, Swan et al., 2002; Stark & Hickson, 2004; Chisolm et al., 2007).

There has been recent renewed interest in the link between hearing impairment and cognitive decline, with some suggesting that hearing aid use may be protective against cognitive decline and dementia (Lin, 2012; Dawes, Emsley et al., 2015). Previous research which assessed cognitive performance as an outcome associated with HA use is inconsistent (Mulrow, Aguilar et al., 1990; Tesch-Römer, 1997; Lehrl et al., 2005; Van Hooren et al., 2005; Acar et al., 2011; Choi et al., 2011; Lin et al., 2011), and no study that we are aware of has examined the long-term protective effects of HA use against cognitive decline. In the present study, there were no differences in cognitive performance or the incidence of cognitive impairment between hearing aid users and non-users. This is not supportive of a robust effect of hearing aid use as being protective against cognitive decline.

There were no significant differences in social engagement or perceived mental health between hearing aid users and non-users. This is consistent with some previous intervention studies which reported that hearing aid use was associated with a reduction in hearing handicap, but not with

any change in social engagement or mental health measures (Tesch-Römer, 1997; Stark & Hickson, 2004). However, one previous RCT reported an improvement in social engagement and a small reduction in symptoms of depression (Mulrow, Aguilar et al., 1990). Note that Mulrow et al's (1990) study was with a select population (elderly white male US veterans with moderate-to-severe hearing loss), and so may not be applicable to wider populations. Another study reported a slight improvement in SF-36 mental health component scores in hearing aid users versus non-hearing aid users over 10 years (Gopinath et al., 2012). It is difficult to interpret this finding however; hearing aid use was not the primary focus of the study, and no data on the demographics nor SF-36 scores for hearing aid users and non-users were reported.

Hearing aid users tended to score slightly better than non-users on a measure of perceived quality of physical health (SF-12 Physical Component Score) in the present study. Hearing aid users continued to demonstrate a higher SF-12 Physical Component Score at 5 and 11 years post-baseline. Hearing aids may promote better general health, perhaps by reducing hearing handicap and promoting a more active, engaged lifestyle. But there was no significant difference in hearing handicap between hearing aid users with their hearing aids and non-users where this was measured. There was also no significant difference on a measure of social engagement between hearing aid users and non-users.

The main strength of the study is that a wide range of outcomes were examined in a population-based sample 5 to 11 years post baseline. We are not aware of any study that has examined outcomes over such a long duration. The impact of hearing aid use on some outcomes (for example, on cognitive performance via amelioration of cognitive decline) may only be observable after a period of several years. The measures used in the present study have

established high validity and reliability, and are widely used in epidemiological studies. A battery of cognitive tests was administered in the 11 year follow-up. Self-reported usage data indicated that most HA users wore their hearing aids consistently.

The present study was observational, and it was not possible to ascribe causal effects to the associations that were observed. Allocation to hearing aid user and non-user groups was not random, and there may be differences between groups that were either not measured or not fully accounted for by statistical adjustment. The proportion of hearing aid users in the present study was small (10.4% at baseline), although comparable to levels that have been reported nationally for the US (Chien & Lin, 2012) and internationally (Shield, 2006; Dawes et al., 2014). It is possible that small differences in outcome were not detectable with the statistical power of the present study. In the case of the cognitive measures, for example, there was a (non-statistically significant) trend for hearing aid users to score more poorly than non-users. However, the study was well-powered to detect medium sized effects. If differences in outcome between hearing and users and non-users do exist, they are likely to be small and may not be clinically relevant. The inclusion of people who use hearing aids occasionally or for only part of the day may have reduced the impact of hearing aids on the outcomes of interest. However, hours of hearing aid use does not necessarily reflect hearing aid benefit (Humes, 1999; Laplante-Lévesque et al., 2013). Additionally, because the present study utilized a population-based sample, the levels of hearing aid use in the present study are likely to reflect the patterns of hearing aid use and the associated benefits that could realistically be expected in real life. Data on the amount of self-reported hearing aid use were available, but other data on factors (such as the type of hearing aid, how well hearing aids were fitted to audiometrically prescribed levels of amplification, use of

alternative communication strategies) were not available. These factors may impact the effectiveness of aural rehabilitation and impact outcomes. Not all measures were included at every time point; additional measures were added to successive waves of assessment. However, the study does provide the most detailed range of outcome measures at the 11-year time point, which can be interpreted in respect to the baseline and pre-baseline characteristics of hearing aid users and non-users. The aim of the study was to compare outcomes for those who began hearing aid use between pre-baseline and baseline, compared those who did not report using hearing aids at baseline. We identified that some HA users became non-users and some non-users became HA users within the 11 year follow-up period. However, most participants remained either HA users or non-users, and analysis of a sub-sample of consistent HA users and non-users yielded similar results to those for the main sample; some positive associations between HA use were found for physical health measures, but not mental health, social engagement or cognitive function.

Conclusion

Few studies have examined broader outcomes associated with hearing aid use including mental health, physical health, social engagement, and cognitive function. No study to our knowledge has examined long-term outcomes of hearing aid use. In the present study, there was no evidence that hearing aids are effective in promoting perceived mental health, cognitive function, or social engagement in the long term. However, hearing aids may be effective in reducing hearing handicap, and may promote better perceived quality of physical health.

Ethical and practical constraints preclude randomized controlled trials of the impact of hearing aid use among people with hearing impairment that utilize the long study durations that would be

required to observe effects on some outcomes (such as on cognitive decline). It would not be ethical to randomize someone with hearing impairment to a 'no hearing aid' condition for a study that would run for several years. An alternative approach is to investigate differences in long-term outcomes in a similar manner to the present study, i.e. by comparing outcomes in hearing aid users versus non-users while controlling statistically for potential confounders. Future studies could examine outcomes in existing longitudinal data sets, or follow people with hearing loss prospectively. Future studies could improve on the present one by investigating factors that may impact on the effectiveness of aural rehabilitation, such as the goodness of hearing aid fit to audiometrically prescribed levels of amplification, the degree of improvement in audibility with hearing aid use, the type of hearing aid, patterns of hearing aid use, use of alternative communication strategies and audiological support.

Acknowledgements

The content is solely the responsibility of the authors and does not necessarily represent the official views of the National Institute on Aging or the National Institutes of Health.

Declaration of interest: This research was undertaken during a visiting scholarship to the University of Wisconsin funded by the US-UK Fulbright Commission and Action on Hearing Loss awarded to PD. The project described was supported by Award Numbers R37AG011099 from the National Institute on Aging, National Eye Institute, and National Institute on Deafness and Other Communication Disorders, EY06594 from the National Eye Institute, and by unrestricted funds from Research to Prevent Blindness (RPB).

References

Acar B., Yurekli M.F., Babademez M.A., Karabulut H. & Karasen R.M. 2011. Effects of hearing aids on cognitive functions and depressive signs in elderly people. *Archives of Gerontology and Geriatrics*, 52, 250-252.

Arlinger S. 2003. Negative consequences of uncorrected hearing loss-a review. *International Journal of Audiology*, 42, 2S17-12S20.

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

Bowie C.R. & Harvey P.D. 2006. Administration and interpretation of the Trail Making Test. *Nature Protocols*, 1, 2277-2281.

Chia E.M., Wang J.J., Rochtchina E., Cumming R.R., Newall P., et al. 2007. Hearing impairment and health-related quality of life: The Blue Mountains hearing study. *Ear & Hearing*, 28, 187-195.

Chien W. & Lin F.R. 2012. Prevalence of hearing aid use among older adults in the United States. *Archives of internal medicine*, 172, 292-293.

Chisolm T., Hnath T., Johnson C.E., Danhauer J.L., Portz L.J.P., et al. 2007. A systematic review of health-related quality of life and hearing aids: Final report of the American Academy of Audiology task force on the health-related quality of life benefits of amplification in adults. *Journal of the American Academy of Audiology*, 18, 151-183.

Choi A.Y., Shim H.J., Lee S.H., Yoon S.W. & Joo E.J. 2011. Is cognitive function in adults with hearing impairment improved by the use of hearing aids? *Clinical Journal of Experimental Otorhinolaryngology*, 4, 72-76.

Cruickshanks K.J., Wiley T.L., Tweed T.S., Klein B.E.K., Klein R., et al. 1998. Prevalence of Hearing Loss in Older Adults in Beaver Dam, Wisconsin The Epidemiology of Hearing Loss Study. *American Journal of Epidemiology*, 148, 879-886.

Cruickshanks K.J., Zhan W. & Zhong W. 2010. Epidemiology of age-related hearing impairment. *The Aging Auditory System*, 259-274.

Dalton D.S., Cruickshanks K.J., Klein B.E.K., Klein R., Wiley T.L., et al. 2003. The impact of hearing loss on quality of life in older adults. *The Gerontologist*, 43, 661-668.

Dawes P., Emsley R., Moore D., Cruickshanks K.J., Fortnum H., et al. 2015. Hearing loss and cognition: the role of hearing aids, social isolation and depression. *PLOS One*.

Dawes P., Fortnum H., Moore D.R., Emsley R., Norman P., et al. 2014. Hearing in middle age: a population snapshot of 40-69 year olds in the UK. *Ear and hearing*, 35.

Folstein M.F., Folstein S.E. & McHugh P.R. 1975. "Mini-mental state": a practical method for grading the cognitive state of patients for the clinician. *Journal of psychiatric research*, 12, 189-198.

Gallacher J., Ilubaera V., Ben-Shlomo Y., Bayer A., Fish M., et al. 2012. Auditory threshold, phonologic demand, and incident dementia. *Neurology*, 79, 1583-1590.

Gopinath B., Schneider J., Hickson L., McMahon C.M., Burlutsky G., et al. 2012. Hearing handicap, rather than measured hearing impairment, predicts poorer quality of life over 10 years in older adults. *Maturitas*, 72, 146-151.

Gopinath B., Wang J.J., Schneider J., Burlutsky G., Snowdon J., et al. 2009. Depressive symptoms in older adults with hearing impairments: the Blue Mountains Study. *Journal of the American Geriatrics Society*, 57, 1306-1308.

Gurgel R.K., Ward P.D., Schwartz S., Norton M.C., Foster N.L., et al. 2014. Relationship of Hearing Loss and Dementia: A Prospective, Population-Based Study. *Otology & Neurotology*, 35, 775-781.

Humes L.E. 1999. Dimensions of hearing aid outcome. *Journal of the American Academy of Audiology*, 10, 26-39.

Jerger J., Chmiel R., Florin E., Pirozzolo F. & Wilson N. 1996. Comparison of conventional amplification and an assistive listening device in elderly persons. *Ear and hearing*, 17, 490-504.

Katz S., Downs T.D., Cash H.R. & Grotz R.C. 1970. Progress in the development of the index of ADL. *Gerontologist*, 10, 20-30.

Kochkin S. & Rogin C. 2000. Quantifying the obvious: The impact of hearing instruments on quality of life. *Hear Rev*, 7, 6-34.

Laplante-Lévesque A., Jensen L.D., Dawes P. & Nielsen C. 2013. Optimal Hearing Aid Use: Focus Groups With Hearing Aid Clients and Audiologists. *Ear & Hearing*, 34, 193–202.

Lawton M.P. & Brody E.M. 1969. Assessment of older people: self-maintaining and instrumental activities of daily living. *Gerontologist*, 9, 179-186.

Lehrl S., Funk R. & Seifert K. 2005. The first hearing aid increases mental capacity. Open controlled clinical trial as a pilot study. *HNO*, 53, 852-862.

Lin F.R. 2012. Hearing loss in older adults. Who's listening? *JAMA*, 307, 1147-1148.

Lin F.R., Ferrucci L., Metter E.J., An Y., Zonderman A.B., et al. 2011. Hearing loss and cognition in the Baltimore Longitudinal Study of Aging. *Neuropsychology*, 25, 763.

Lin F.R., Yaffe K., Xia J., Xue Q., Harris T.B., et al. 2013. Hearing loss and cognitive decline in older adults. *JAMA internal medicine*, 173, 293-299.

Lin M.Y., Gutierrez P.R., Stone K.L., Yaffe K., Ensrud K.E., et al. 2004. Vision impairment and combined vision and hearing impairment predict cognitive and functional decline in older women. *Journal of the American Geriatrics Society*, 52, 1996-2002.

Lindenberger U. & Baltes P.B. 1994. Sensory functioning and intelligence in old age: a strong connection. *Psychology and aging*, 9, 339.

Mackenbach J.P., Kunst A.E., Cavelaars A.E., Groenhof F., Geurts J.J., et al. 1997. Socioeconomic inequalities in morbidity and mortality in western Europe. *The lancet*, 349, 1655-1659.

Marmot M., Allen J., Bell R., Bloomer E. & Goldblatt P. 2012. WHO European review of social determinants of health and the health divide. *The Lancet*, 380, 1011-1029.

Moyer V.A. 2012. Screening for Hearing Loss in Older Adults: US Preventive Services Task Force Recommendation Statement. *Annals of internal medicine*, 157, 655-661.

Mulrow C.D., Aguilar C., Endicott J.E., Tuley M.R., Velez R., et al. 1990. Quality-of-life changes and hearing impairment. A randomized trial. *Annals of Internal Medicine*, 113, 188-194.

Mulrow C.D., Aguilar C., Endicott J.E., Velez R., Tuley M.R., et al. 1990. Association between hearing impairment and the quality of life of elderly individuals. *Journal of the American Geriatrics Society*, 38, 45.

Peters C.A., Potter J.F. & Scholer S.G. 1988. Hearing impairment as a predictor of cognitive decline in dementia. *Journal of the American Geriatrics Society*, 36, 981-986.

Salthouse T.A. 1991. *Theoretical perspectives on cognitive aging*. Hillsdale, NJ: Lawrence Erlbaum Assocaites.

Schmidt M. 1996. *Rey auditory verbal learning test: a handbook*: Western Psychological Services Los Angeles.

Shield B. 2006. Evaluation of the social and economic costs of hearing impairment. Belgium: hear-it AISBL.

Stark P. & Hickson L. 2004. Outcomes of hearing aid fitting for older people with hearing impairment and their significant others. *International Journal of Audiology*, 43, 390-398.

Strauss E., Sherman E.M.S. & Spreen O. 2006. *A Compendium of Neuropsychological Tests: Administration, Norms, and Commentary*. New York, N.Y.: Oxford University Press.

Strawbridge W.J., Wallhagen M.I., Shema S.J. & Kaplan G.A. 2000. Negative Consequences of Hearing Impairment in Old Age A Longitudinal Analysis. *The Gerontologist*, 40, 320-326.

Tesch-Römer C. 1997. Psychological effects of hearing aid use in older adults. *The Journals of Gerontology Series B: Psychological Sciences and Social Sciences*, 52, P127-P138.

Tolson D., Swan I. & Knussen C. 2002. Hearing disability: a source of distress for older people and carers. *British journal of nursing*, 11, 1021-1025.

Ulhmann R.F., Larson E.B., Rees T.S., Koepsell T.D. & Duckert L.G. 1989. Relationship of hearing impairment to dementia and cognitive dysfunction in older adults. *JAMA*, 261, 1916-1919.

Van Hooren S.A.H., Anteunis L.J.C., Valentijn S.A.M., Bosma H., Ponds R., et al. 2005. Does cognitive function in older adults with hearing impairment improve by hearing aid use? *International journal of audiology*, 44, 265-271.

Ventry I.M. & Weinstein B.E. 1983. Identification of elderly people with hearing problems. *Asha*, July, 37-43.

Vestergaard Knudsen L., Oberg M., Nielsen C., Naylor G. & Kramer S.E. 2010. Factors influences help seeking, hearing aid uptake, hearing aid use and satisfaction with hearing aids: A review of the literature. *Trends in Amplification*, 14, 127-154.

Ware J.E., Kosinski M. & Keller S.D. 1996. A 12-Item Short-Form Health Survey: construction of scales and preliminary tests of reliability and validity. *Medical care*, 34, 220-233.

Wechsler D. 1991. *WAIS-R Wechsler adult intelligence scale-III.* . New York, N.Y.: Psychological Corporation.

Yueh B., Souza P.E., McDowell J.A., Collins M.P., Loovis C.F., et al. 2001. Randomized trial of amplification strategies. *Archives of Otolaryngology - Head & Neck Surgery*, 127, 1197.

532 Table 1. Demographic and hearing characteristics of hearing aid users and non-users at baseline

Characteristic	Hearing aid users (n=69)	Non-users (n=597)	P-value[b]
Demographics			
Age (yrs) (SD)	69.5 (9.8)	68.0 (9.7)	.20
Male gender (%)	68.1	74.4	.26
Education (%)			
0-11 yrs	36.2	30.8	.71
12 yrs	44.9	46.2	
13-15 yrs	11.6	12.1	
16+ yrs	7.3	10.9	
Household income (%)			
< $10,000	5.2	11.3	.32
$10,000-19,999	24.1	28.1	
$20,000-29,999	29.3	20.0	
$30,000-44,999	25.9	22.9	
$45,000+	15.5	17.8	
Caucasian (%)	100.0	99.2	-
Hearing			
Pure tone average[a] (SD)	38.9 (10.5)	29.8 (9.0)	< .0001

533 [a]Average of hearing thresholds at .5, 1, 2 and 4 kHz in the better ear, in dB HL.
534 [b]P-values are from the chi-square test for association (categorical comparisons), or t-test for difference in means.
535

Table 2. Communication, cognition, and health characteristics of hearing aid users and non-users at pre-baseline, baseline, 5 years and 11 years.

	Pre-baseline [a]			Baseline [a]			5 year outcomes [a]			11 year outcomes [a]		
Characteristic	Hearing aid users (n=69)	Non-users (n=597)	P-value[b]	Hearing aid users (n=69)	Non-users (n=597)	P-value[b]	Hearing aid users (n=50)	Non-users (n=440)	P-value[b]	Hearing aid users (n=31)	Non-users (n=271)	P-value[b]
Communication												
Hearing handicap (HHIE-S) score, with hearing aid	-	-	-	10.2 (1.3)	-	-	10.5 (1.5)	-	-	-	-	-
Hearing handicap (HHIE-S) score, without hearing aid	11.9 (0.9)	6.8 (0.3)	< .0001	19.8 (1.0)	8.3 (0.3)	< .0001	21.2 (1.4)	10.8 (0.4)	< .0001	22.6 (1.9)	12.4 (0.6)	< .0001
Cognition												
MMSE score	-	-	-	26.7 (0.4)	26.5 (0.1)	.62	26.8 (0.4)	26.9 (0.1)	.77	25.9 (0.5)	26.9 (0.2)	.10
Trail-making test A score (sec)	-	-	-	-	-	-	-	-	-	65.0 (7.8)	57.5 (2.4)	.37
Trail-making test B score (sec)	-	-	-	-	-	-	-	-	-	147.5 (14.4)	148.3 (4.4)	.96
AVLT score (0-15)	-	-	-	-	-	-	-	-	-	3.2 (0.5)	4.1 (0.1)	.09
DSST score (0-93)	-	-	-	-	-	-	-	-	-	34.0 (2.1)	35.3 (0.7)	.59
VFT score	-	-	-	-	-	-	-	-	-	26.2 (2.3)	29.2 (0.7)	.21
Physical health												
SF-12 HRQOL survey- Physical Component Score	-	-	-	46.1 (1.2)	44.5 (0.4)	.24	46.0 (1.6)	42.7 (0.5)	.06	46.2 (2.1)	41.2 (0.7)	.03
# limitations on ADL	-	-	-	0.3 (0.1)	0.5 (0.0)	.12	0.7 (0.2)	1.0 (0.1)	.26	0.7 (0.3)	1.0 (0.1)	.39
# limitations on IADL	-	-	-	1.4 (0.2)	1.3 (0.1)	.67	1.9 (0.4)	2.1 (0.1)	.68	2.5 (0.6)	2.4 (0.2)	.74
Social engagement												
TV/computer/reading (hrs/wk)	-	-	-	-	-	-	37.9 (2.9)	35.6 (0.9)	.45	-	-	-
Mental health												
SF-12 HRQOL survey- Mental Component Score	-	-	-	53.6 (0.9)	54.3 (0.3)	.50	54.7 (1.1)	55.2 (0.4)	.68	56.7 (1.5)	54.7 (0.5)	.19

[a]Means and standard errors (SE) are adjusted for age, gender, and $PTA_{0.5,1,2,4\ kHz,\ better\ ear}$

[b]P-values are from ANCOVA models adjusted for age, gender, and $PTA_{0.5,1,2,4\ kHz,\ better\ ear}$

Characteristic	5 year outcomes least squares mean: Hearing aid users (n=26)	5 year outcomes least squares mean: Non-users (n=200)	P-value[a]	11 year outcomes least squares mean: Hearing aid users (n=26)	11 year outcomes least squares mean: Non-users (n=200)	P-value[a]
Communication						
Hearing handicap (HHIE-S) score, without hearing aid	26.0	8.6	< .0001	23.9	10.2	< .0001
Cognition						
MMSE score	27.7	27.5	.68	26.7	27.0	.70
Trail-making test A score (sec)	-	-	-	55.1	56.4	.87
Trail-making test B score (sec)	-	-	-	143.9	150.0	.71
AVLT score (0-15)	-	-	-	3.4	4.0	.23
DSST score (0-93)	-	-	-	36.2	34.6	.50
VFT score	-	-	-	26.4	28.8	.38
Physical health						
SF-12 HRQOL survey- Physical Component Score	47.8	43.6	.09	46.2	41.6	.07
# limitations on ADL	0.5	0.4	.72	0.2	1.0	.04
# limitations on IADL	1.1	1.1	.98	1.7	2.2	.40
Social engagement						
TV/computer/reading (hrs/wk)	39.2	34.8	.27			-
Mental health						
SF-12 HRQOL survey- Mental Component Score	54.5	57.1	.11	57.5	54.8	.12

[a]P-values are from ANCOVA models using t-tests for least squares means adjusted for age, gender, and $PTA_{0.5,1,2,4}$ kHz, better ear

Includes only those consistently using or consistently not using hearing aids from EHLS2 through EHLS4.