Original Article

What Keeps Older Adults With Hearing Impairment From Adopting Hearing Aids?

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Abstract

The aim of this study was to compare elderly individuals who are hearing impaired but inexperienced in using hearing aids (hearing aid non-users; HA-NU) with their aided counterparts (hearing aid users; HA-U) across various auditory and non-auditory measures in order to identify differences that might be associated with the low hearing aid uptake rate. We have drawn data of 72 HA-NU and 139 HA-U with a mild-to-moderate hearing loss, and matched these two groups on the degree of hearing impairment, age, and sex. First, HA-NU and HA-U were compared across 65 auditory, cognitive, health-specific, and socioeconomic test measures as well as measures assessing technology commitment. Second, a logistic regression approach was performed to identify relevant predictors for using hearing aids. Finally, we conducted a sensitivity analysis for the matching approach. Group comparisons indicated that HA-NU perceive their hearing problem as less severe than their aided counterparts. Furthermore, HA-NU showed worse technology commitment and lower socioeconomic status than HA-U. The logistic regression revealed self-reported hearing performance, technology commitment, and the socio-economic and health status as the most important predictors for using hearing aids.

Keywords

hearing loss, aging, technologies, socioeconomic status, cognition

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Introduction

Hearing impairment in older adults is a major public health issue in developed countries. Despite available devices and major technical progress in the last decades, however, only a minority of individuals with hearing difficulties, particularly with mild levels of hearing loss, are using hearing devices. For example, Chien and Lin (2012) reported a prevalence of hearing aid use ranging from 4.3% to 22.1% in elderly individuals with a mild-to-moderate hearing loss in the United States, and Bisgaard and Ruf (2017) recently found a hearing aid adoption rate ranging from 14.7% to 27.1% in individuals with mild levels of hearing loss across all ages in Germany, France, and the United Kingdom.

This is especially relevant because a number of studies point toward possible negative side effects in hearing aid candidates not using hearing devices: Untreated hearing loss affects one's quality of life (for review see Chisolm et al., 2007), decreases social engagement, increases symptoms of depression (for review see Arlinger, 2003), may increase the risk of falling (Lin & Ferrucci, 2012) and, in addition, may have a negative impact on cognitive performance (Amieva et al., 2015; Dawes et al., 2015). Treating hearing loss with hearing aids raises the ability to take part in everyday life situations, improves the physical, social, emotional, and mental quality of life and increases listening skills toward other persons (for review see Ferguson et al., 2017). Hence, it is of major interest to raise the overall treatment rate. Therefore, it is necessary to identify reasons why hearing loss often remains untreated and to investigate how individuals

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with hearing loss who are not using hearing devices differ from their treated counterparts.

Due to the gradual onset of age-related hearing loss (Davis et al., 2007), many individuals are unaware of their impairment. This might be one reason for the low uptake rate, particularly in individuals with mild levels of hearing loss. Aside from that, other factors, such as, for example, self-reported hearing problems and demographic factors, have previously been investigated in relation to undertreatment (e.g., Cox, Alexander, & Gray, 2005; Dawes et al., 2015; Fischer et al., 2011; Gopinath et al., 2011; Heffernan, Coulson, Henshaw, Barry, & Ferguson, 2016; Humes, Wilson, & Humes, 2003; Meyer, Hickson, Lovelock, Lampert, & Khan, 2014; Ng & Loke, 2015; Öberg, Marcusson, Nagga, & Wressle, 2012; Pronk et al., 2017; Southall, Gagne, & Jennings, 2010; for reviews see Barker, Leighton, & Ferguson, 2017; Jenstad & Moon, 2011; Knudsen, Oberg, Nielsen, Naylor, & Kramer, 2010; McCormack & Fortnum, 2013; Meyer & Hickson, 2012).

In their review, Knudsen et al. (2010) identified only one variable, namely self-reported hearing disability that positively affected all outcome measures related to help seeking, hearing aid uptake and use. Sex showed no influence on any of the outcome measures and the vast majority of studies reported the same for age. In this context, however, the authors pointed out that most of the studies focused on elderly participants and that broader age ranges are needed for general conclusions. Moreover, a review by Jenstad and Moon (2011) found sex to be a mediating variable between the hearing aid uptake and stigma, locus of control (the faith in the ability to personally control what happens to oneself), and the degree of hearing loss — three factors that were identified in several studies as predictor variables for the uptake rate.

For further factors, such as technology commitment and use, as well as the socioeconomic status, data were limited or mixed results were reported. For example, either a positive or no association was found between technology and hearing aid use (Gonsalves & Pichora-Fuller, 2008; Stieglitz Ham, Bunn, Meyer, Khan, & Hickson, 2014). The same applies to the socioeconomic status and hearing aid uptake and use (Garstecki & Erler, 1998; Gussekloo et al., 2003; Humes et al., 2003; Humphrey, Herbst, & Faurqi, 1981; Jerram & Purdy, 2001; Lupsakko, Kautiainen, & Sulkava, 2005). To our knowledge, no studies have investigated this issue in Germany so far.

Summing up, a majority of individuals with hearing impairment are not using hearing aids. Because of the negative side effects of untreated hearing loss, it is of major interest to target these individuals with hearing support. To this end, it is necessary to gain a better understanding for possible reasons for the low uptake rate and to investigate differences in hearing aid users and non-users with the same degree of hearing loss, as these differences might be related to the undertreatment. A growing body of evidence suggests that self-reported hearing loss is positively associated with hearing aid uptake and use. However, the role of technology commitment and use, and the socioeconomic status, for example, still seems incompletely understood, particularly in Germany. Here, we addressed these issues by investigating a sample of elderly hearing aid non-owners without hearing aid experience (hearing aid non-users; HA-NU) and by contrasting them to their aided counterparts (hearing aid users; HA-U) using various auditory and non-auditory test measures, such as measures assessing technology commitment and use, as well as the socioeconomic status. Both groups comprised individuals with a mild-to-moderate hearing loss (26 dB HL $\leqslant$ pure-tone average (PTA) $\leqslant$ 60 dB HL, whereat PTA was defined as the average dB HL value across the frequencies 0.5, 1, 2, and 4 kHz of the better ear; World Health Organization [WHO], 1991), and were matched on the degree of hearing impairment, age, and sex.

The aims of this study were threefold: (1) We compared elderly HA-NU and HA-U across various auditory, cognitive, health-specific, and socioeconomic test measures as well as measures assessing technology commitment in order to identify differences that might be associated with the low hearing aid uptake rate. (2) Within a logistic regression approach, we aimed at identifying those test measures that predict whether an individual is an HA-U or an HA-NU. (3) We conducted a sensitivity analysis to verify the impact of matching both groups on the degree of hearing impairment, age, and sex, by repeating aforementioned analysis steps using unmatched HA-NU and HA-U samples.

Materials and Methods

We analyzed data from the database of the Hörzentrum Oldenburg GmbH, described in more detail by Gieseler et al. (2017). The database comprises more than 2,400 individuals and was intended to characterize an existing cohort. Participants of this study were selected from a subset of 595 individuals who had completed a test battery comprising auditory and cognitive tests as well as comprehensive self-report questionnaires. The measurements were performed by trained professional staff at the facilities of the Hörzentrum. The test measures entering the current analysis were chosen by the authors in a knowledge-driven approach and are described in more detail below.

The studies were approved by the local ethics committee of the University of Oldenburg and performed according to the Declaration of Helsinki. All participants gave their written informed consent prior to the study, received a monetary compensation for participation, and were fully anonymized for this analysis.

Test Measures

Auditory measures. In order to assess hearing performance, the *PTA* of the audiogram's air conduction measurement was submitted to the analysis dataset (see Supplementary Table S1).[1] The variable *PTA* was calculated based on dB HL values across the frequencies 0.5, 1, 2, and 4 kHz of the better ear.

Furthermore, the *50%-SRT* (speech reception threshold) of the Goettingen sentence test by Kollmeier and Wesselkamp (1997), a speech-recognition-in-noise test, entered the analysis (see Supplementary Table S1).

All individuals participated unaided in the audiogram and the speech-recognition-in-noise test, that is, HA-U were measured without their devices.

Cognitive measures. The German vocabulary test (Wortschatztest) by Schmidt and Metzler (1992) measures verbal intelligence, which is seen as an indicator of crystallized and general intellectual abilities (Schmidt & Metzler, 1992). It is measured by the number of correctly identified words among similar non-words, resulting in a total raw score that was used for the analysis (*Verbal intelligence*, see Supplementary Table S1).

Moreover, six variables derived from the five subtests of the DemTect (Kalbe et al., 2004), a screening test for dementia, served as further cognitive measures for the analysis: *Wordlist*, *Semantic verbal fluency*, *Number transcoding*, *Digit span reverse*, *Wordlist delayed recall*, as well as a transformed sum score composed of the five aforementioned variables and referred as to *Cognitive sum score* (see Supplementary Table S1). The variable *Wordlist* is the achieved raw score based on recalls of a 10-item wordlist in two trials taxing verbal short-term memory. *Semantic verbal fluency* is measured by a semantic word fluency task in which participants have to name as many supermarket items as possible within one minute. In the number transcoding task, participants have to transcode numbers into numerals and vice versa, resulting in the variable *Number transcoding* that assesses cognitive flexibility. The digit span reverse subtest requires repeating number sequences in backward order measuring working memory capacity (variable *Digit span reverse*). At the end of the DemTect test, participants are prompted to recall the wordlist from the beginning, yielding the variable *Wordlist delayed recall* that assesses verbal long-term memory. Finally, a transformed total score independent of age was calculated according to Kalbe et al. (2004) and labeled as *Cognitive sum score*.

Self-reports. Self-reports were obtained from questions in the questionnaire that addressed the topics hearing, health status, socioeconomic status, technology commitment, and usage habits of media devices.

Hearing. The topic hearing covers questions regarding the hearing history and demands on sound quality, as well as usage of hearing aids. Out of those, the following nine variables entered the analysis dataset: *Hearing loss detected*, *Duration of hearing loss*, *Subjective hearing problems in quiet*, *Subjective hearing problems in noise*, *Demand on sound quality of audio devices*, *Current hearing aid use*, *Duration of hearing aid use*, *Daily duration of hearing aid use*, and *One- or two-sided hearing aid* (see Supplementary Table S1).

Health status. In order to assess the health status, participants were asked questions of the German version of the SF-12 Health Survey (Bullinger & Kirchberger, 1998; Bullinger, Kirchberger, & Ware, 1995). Beyond the 12 single questions, two summarizing test scores, the *Physical sum score* and the *Mental sum score*, standardized to a norm population, entered the present analysis (Bullinger & Kirchberger, 1998), as well as the mean value of the two aforementioned scores that was referred as to *Health mean score* (see Supplementary Table S1).

Socioeconomic status. Questions regarding *School graduation*, *Professional degree*, *Main professional occupation*, and *Net income per household* were completed by the participants, and additionally to those four items, a summarizing score indexing the socioeconomic status entered the analysis. This so-called *Socioeconomic status sum score* was computed according to Winkler and Stolzenberg (2009) (see Supplementary Table S1).

Technology commitment and usage habits of media devices. Technology commitment was evaluated using 12 questions regarding the topics technology competence, technology acceptance, and technology control (Neyer, Felber, & Gebhardt, 2012). In addition to these 12 single items, the summarizing scores *Technology competence*, *Technology acceptance*, *Technology control*, as well as the overall mean score referred to as *Technology commitment mean score* were used for the analysis (see Supplementary Table S1). Moreover, eight questions regarding the usage habits of media devices, such as, for example, frequencies of using a PC or notebook, MP3 player, or a smartphone, served as test measures for the analysis, as well as the summarized score labeled *Usage habits sum score* (see Supplementary Table S1).

Participants

In order to focus on elderly individuals, participants aged younger than 60 years were excluded from the 595 individuals. Furthermore, we excluded participants with normal hearing ($PTA < 26$ dB HL; WHO, 1991) and participants with a severe-to-profound hearing impairment ($PTA \geqslant 61$ dB HL; WHO, 1991). We also excluded individuals with an asymmetric hearing loss (i.e., individuals with a PTA difference between their left and right ear >10 dB HL). Therefore, corresponding PTA values across the audiometric frequencies 0.5, 1, 2, and 4 kHz were calculated, and if one of the four hearing threshold values was missing, PTA values were determined by averaging the remaining three hearing thresholds; however, participants showing two or more missing values across these four hearing thresholds were excluded. In addition, individuals with air-bone gaps >10 dB HL were excluded. For this purpose, differences between air and bone conduction thresholds of the better ear were calculated across the audiometric frequencies 0.5, 1, 2, and 4 kHz. Afterwards, we averaged these dB HL values for both air and bone conduction to test the aforementioned criterion. We also excluded individuals who reported hearing aid experience but indicated an average daily wearing period of less than one hour within the last 14 days. In addition, individuals with a not clearly defined status of hearing aid experience or those with a cochlear implant were excluded. Finally, we excluded individuals with a native language other than German, with suspicion of dementia (DemTect scores of $\leqslant 8$; Kalbe et al., 2004), or with more than 25% missing values.

Application of the exclusion criteria resulted in a sample of 211 adults of 60 years or older with a mild-to-moderate sensorineural and symmetric hearing loss. Of those, 72 were hearing aid non-users (mean $PTA = 33.4 \pm 5.8$ dB HL; mean $age = 70.6 \pm 5.1$ years; 29 (40.3%) females) and 139 were hearing aid users (mean $PTA = 44.3 \pm 8.0$ dB HL; mean $age = 72.1 \pm 6.1$ years; 45 (32.4%) females).

Matching Algorithm

Assuming that group differences in some of the test measures among hearing aid non-users (HA-NU) and hearing aid users (HA-U) were mediated by group differences in hearing performance or demographics, we controlled for possible confounding effects by matching on the variables *PTA*, *Age*, and *Sex* in a 1:1 ratio. To this end, a matching algorithm was implemented and applied to the two groups consisting of all potential HA-NU ($n = 72$) and HA-U ($n = 139$). The algorithm proceeds as follows (see Figure 1): It starts by randomly selecting one HA-NU. In a second step, all potential matching partners from the HA-U group are identified who meet the following matching criteria: *PTA* and *Age* of the matching partners have to be in the range of ± 3 dB HL of the PTA value and ± 5 years of the age of the selected non-user, respectively. In addition, the potential matching partners have to be of same *Sex* as the selected non-user. If no potential matching partner can be identified, the individual is excluded from the pool of potential HA-NU, another non-user is randomly selected and the algorithm proceeds with step number two. If at least one potential matching partner is identified, the one with age closest to the hearing aid non-user is selected. In case multiple HA-U have the same closest age, the HA-U is selected at random. The selected HA-NU and his or her matching partner are excluded from the pools of potential HA-NU and HA-U and separately stored as individuals of the two analysis datasets. The algorithm tries to find a matching partner for all hearing aid non-users and stops thereafter.

When the algorithm is repeated multiple times, the resulting samples of HA-NU and HA-U slightly differ due to some random variability. Consequently, in order to increase precision, we applied the matching algorithm multiple times. As we simultaneously wanted to avoid high inaccuracy (bias), we looked for a number of repetitions that is not too large. After testing some numbers of repetitions, we decided to apply the matching algorithm 20 times and then summarized the results of our analysis across the 20 samples of HA-NU and the 20 samples of HA-U.

Analysis

Aiming at identifying differences between hearing aid non-users and hearing aid users possibly being associated with the low hearing aid uptake rate, we first compared HA-NU with HA-U matched on the variables *PTA*, *Age*, and *Sex* using various auditory, cognitive, health-specific, and socioeconomic test measures as well as measures assessing technology commitment. In a second step, we performed a stepwise logistic regression approach in order to relate relevant predictors among the test measures to the use or non-use of hearing aids.

For this, we grouped the 65 measures of the test battery in a knowledge-driven approach into six subject areas and labeled those as follows: *Matching* (comprising 3 test measures), *Hearing* (10), *Cognition* (7), *Health status* (15), *Socioeconomic status* (5), and *Technology commitment and usage habits of media devices* (25). All variables entering the analysis are shown in Supplementary Table S1 grouped according to the six

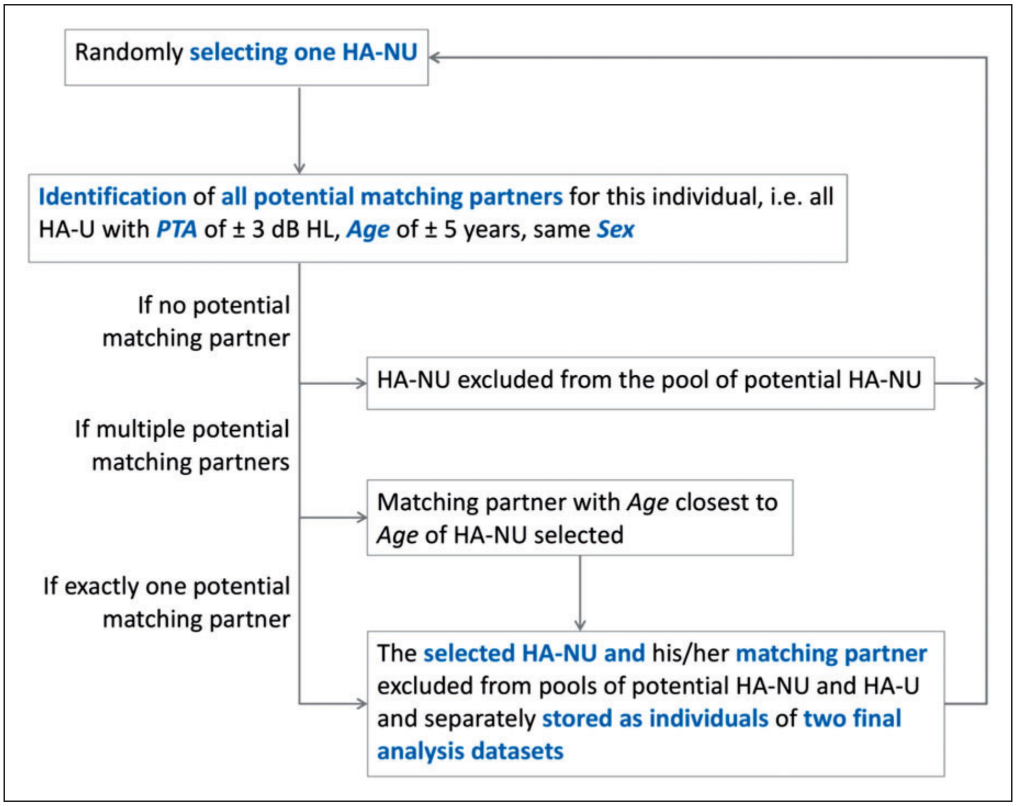

Figure 1. Matching algorithm. Shown are the steps of the matching algorithm that was used to balance HA-NU and HA-U in a 1:1 ratio with respect to the variables *PTA*, *Age*, and *Sex*.
HA-NU = hearing aid non-user; HA-U = hearing aid user.

subject areas. After the matching algorithm had been repeated 20 times (see above), datasets of the 20 samples of HA-NU and the 20 samples of HA-U, each comprising 65 variables, were pooled together yielding a final analysis dataset. In this dataset, the proportion of missing values was 0.82%.

Descriptive Comparisons Between HA-NU and HA-U

In order to identify characteristics of individuals with hearing impairment who are not yet provided with hearing aids (HA-NU), these individuals were contrasted to their aided counterparts (HA-U), and both groups were compared based on distributions of the test measures. For categorical variables, relative frequency distributions (percentages) were compared between HA-NU and HA-U using bar charts or frequency tables, whereas boxplots were used for depicting continuous variables. In frequency tables, the proportion of missing values per question is reported when at least one missing value occurred.

To support descriptive comparisons, we determined effect sizes using Cohen's d (Cohen, 1988) for a pool of representative test measures for the subject areas. To this end, per test and per questionnaire topic one summarizing score was selected resulting in the following eight variables: *50%-SRT* (subject area *Hearing*), *Subjective hearing problems in quiet (Hearing)*, *Verbal intelligence (Cognition)*, *Cognitive sum score (Cognition)*, *Health mean score (Health status)*, *Socioeconomic status sum score (Socioeconomic status)*, *Technology commitment mean score (Technology commitment and usage habits of media devices)*, and *Usage habits sum score (Technology commitment and usage habits of media devices)*. We did not consider variables of the subject area *Matching*, as we assumed no differences after matching HA-NU and HA-U on the variables *PTA*, *Age*, and *Sex*. A Cohen's d of 0.2, 0.5, and 0.8 is commonly interpreted as a small, medium, and large effect, respectively (cf. Cohen, 1988).

For graphical representations and calculations of effect size, observations with missing values were removed in the respective variables.

Statistical Analysis of HA-NU and HA-U

In order to identify relevant predictors for the use of hearing aids, a stepwise logistic regression algorithm was applied. We therefor used an indicator variable for being a HA-U versus being a HA-NU as outcome variable, and to avoid high multicollinearity, we used eight representative variables for the subject areas, which were described above as potential predictor variables. Likewise, we did not consider variables of the subject area *Matching*, as we here assumed no direct influence of these measures on the outcome variable after balancing HA-NU and HA-U with respect to the variables *PTA*, *Age*, and *Sex*. The variable *Subjective hearing problems in quiet* was transformed into a dummy coded variable comprising two possible realizations: *no-to-very slight* and *medium-to-very strong hearing problems*. Without dichotomizing this variable, cell counts were in parts too small so that the fitting algorithm did not converge. For this analysis, missing values were imputed by applying mean imputation (Wilks, 1932).

Stepwise variable selection. For the stepwise regression approach, which is a combination of forward selection and backward elimination, we applied the R-function stepAIC of the R-package MASS by using the Akaike information criterion (AIC; Akaike, 1973) as model selection criterion (R Core Team, 2017).

Logistic regression. We performed a logistic regression approach using the indicator variable for being a HA-U versus being a HA-NU and the eight potential predictor variables into the stepwise algorithm stepAIC. Here, as for the descriptive comparisons, the analysis dataset consisted of the 20 samples of HA-NU and the 20 samples of HA-U. This resulted in 20 logistic regression models. To summarize the results, we first counted the frequencies of predictor selection across the 20 regression models. A final logistic model was fitted using all predictors that were selected by stepAIC among the former approaches and odds ratios as well as corresponding 95% confidence intervals (CI) were calculated.

Furthermore, in order to examine the goodness of fit of the logistic regression models, we calculated the mean deviance of the resulting models across the 20 stepwise regression approaches. The deviance statistic compares the maximum value of the log-likelihood of the fitted regression model to the value of the log-likelihood of the saturated model (cf. Fahrmeir, Kneib, Lang, & Marx, 2013). Smaller deviance indicates a better model fit. In order to evaluate the mean deviance of the 20 regression models, we compared this value with the mean null deviance. Here, the null deviance uses the null model, that is, the model including the intercept only and the saturated model for assessments. When the mean deviance of the regression models is smaller than the mean null deviance, the resulting models are on average better (according to the deviance) than the models including the intercept only.

Sensitivity Analysis for Matching

In order to verify the impact of balancing the two groups with respect to the degree of hearing loss, age, and sex, we additionally conducted the descriptive comparisons and the logistic regression approach to the dataset with all 221 potential HA-NU and HA-U – not being matched on the variables *PTA*, *Age*, and *Sex*, and compared the results with the findings of matched groups.

For data management programs, the statistical SAS software version 9.4 (SAS Institute, 2012), and for analysis programs, the software R version 3.4.2 (R Core Team, 2017) was used.

Results

Descriptive Comparisons Between HA-NU and HA-U

To find out how individuals with hearing impairment who are not using hearing devices differ from their aided counterparts, HA-NU and HA-U were descriptively compared using test measures assessing the subject areas *Matching*, *Hearing*, *Cognition*, *Health status*, *Socioeconomic status*, and *Technology commitment and usage habits of media devices*.

Matching. The 1:1 multiple matching on the variables *PTA*, *Age*, and *Sex* between hearing aid non-users and users resulted in 20 samples with a median sample size of 45 HA-NU and 45 HA-U, ranging from 44 to 47. There were 32.9% females and 67.1% males in the groups of HA-NU and HA-U. The variables *Age* and *PTA* showed similar distributions among HA-NU (mean age $= 71.7 \pm 5.1$ years, mean PTA $= 36.2 \pm 5.5$ dB HL) and HA-U (mean age $= 72.2 \pm 5.0$ years, mean PTA $= 36.7 \pm 5.3$ dB HL).

From 72 potential hearing aid non-users and 139 hearing aid users, the matching algorithm selected 62 and 65 individuals at least once across the 20 matching runs, respectively, with about half of them being included in all 20 analysis datasets ($n = 31$ HA-NU, $n = 29$ HA-U).

Hearing. With respect to the subject area *Hearing*, we compared the frequency distributions of ten test measures between HA-NU and HA-U, whereof five were used to describe the hearing history and hearing aid use of the volunteers in more detail: The median self-reported test measure *Duration of hearing problems* was *five-to-ten years* in both HA-NU and HA-U, ranging from having had *no hearing problems at all* (10.9%) to *more than 20 years* (11.5%) in HA-NU, and from having had experienced *hearing problems for at least one year* (11.2%) to *more than 20 years* (6.6%) in HA-U. All HA-U reported that they were currently using their hearing aid(s) and had been wearing them for at least one hour per day during the previous 14 days (*Current hearing aid use* and *Daily duration of hearing aid use*). The median self-reported daily wearing period during the previous 14 days had been *eight hours and more*, supporting that the investigated HA-U had indeed been using their hearing aids regularly and had been experienced. Of the HA-U, 98.9% were supported by bilateral hearing aids, while 0.7% reported using a unilateral hearing aid (the remaining 0.4% stem from missing values; *One- or two-sided hearing aid*). The average provisioning period amounted to 5.7 ± 3.6 years ranging from *one* to *15 years* (14.6% missing values; *Duration of hearing aid use*).

Distributions of the remaining five test measures (*Hearing loss detected*, *Subjective hearing problems in quiet*, *Subjective hearing problems in noise*, *Demand on sound quality of audio devices*, and the *50%-SRT*) are shown in Figure 2. Interestingly, all of the HA-U seemed to be aware of their hearing loss, whereas 12.9% of the HA-NU indicated that no hearing loss was detected. Furthermore, HA-NU and HA-U differed in the measures *Subjective hearing problems in quiet* and *in noise*: More than twice as many hearing aid users (81.1%) as non-users (36.5%) reported moderate problems in quiet, and slightly more HA-NU reported no-to-slight problems in noise, whereas slightly more HA-U reported medium-to-very strong problems in noise. Furthermore, HA-NU seemed to understand speech in noise slightly better than HA-U, indicated by lower values in the unaided speech reception threshold (median *50%-SRT* = −1.9 dB SNR in HA-NU, median *50%-SRT* = −1.5 dB SNR in HA-U). Effect sizes (ES) for the variables *Subjective hearing problems in quiet* and *50%-SRT* were 0.96 and 0.24, respectively.

Cognition. Among the two groups, no differences were found in the cognitive measures *Verbal intelligence*, *Wordlist*, and *Number transcoding*; whereas HA-NU showed lower (i.e., worse) values in the *Cognitive sum score* than HA-U driven by differences in the distributions of *Semantic verbal fluency*, *Digit span reverse*, and *Wordlist delayed recall*, as shown in Figure 3. For the two variables, *Verbal intelligence* and *Cognitive sum score* ES were 0.23 and 0.27, respectively.

Health status. Combined results of the SF-12 questions are shown in Figure 4. Boxplots of the *Physical* and *Mental sum score* revealed similar median values but a greater dispersion in HA-NU. On average, HA-NU seemed to report a slightly worse health status in comparison to their aided counterparts. For more details see Supplementary Table S2, where each single health question of the SF-12 and its percentages across the response possibilities are listed. ES for the summarizing *Health mean score* was 0.47.

Socioeconomic status. Summarized results of the *Socioeconomic status* among HA-NU and HA-U are shown in Figure 5. Interestingly, HA-NU seemed to have a lower socioeconomic status than their aided counterparts (median *Socioeconomic status sum score* = 11 points in HA-NU, median *Socioeconomic status sum score* = 14 points in HA-U). In Supplementary Figure S3, the detailed relative frequency distributions

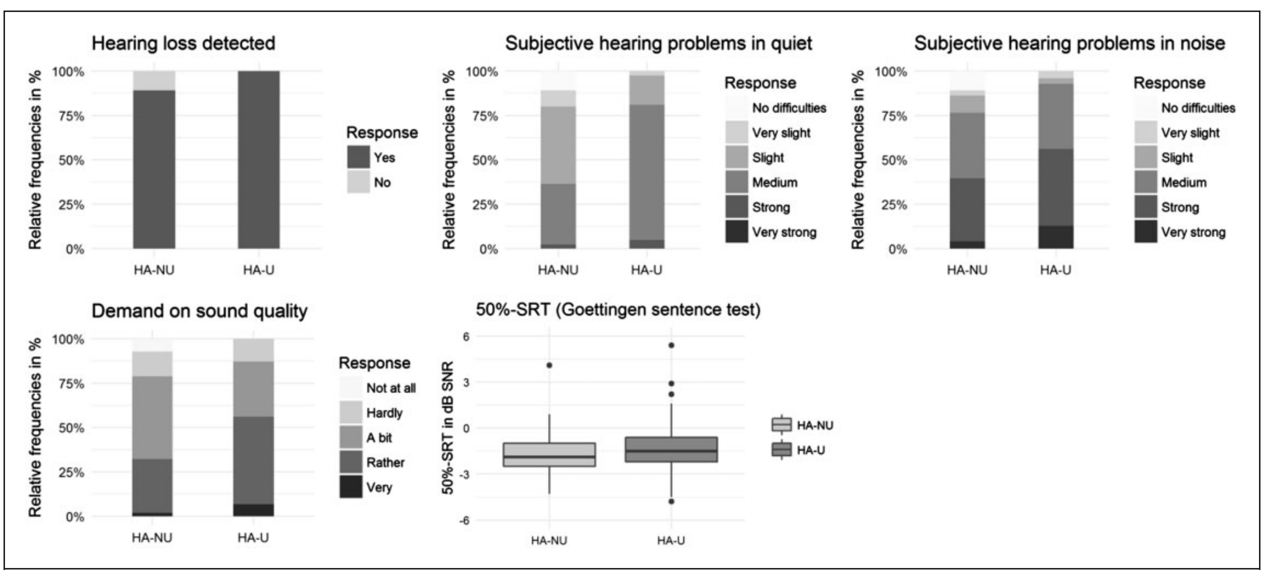

Figure 2. Hearing performance of HA-NU and HA-U. Percentages across the different response categories of four questions regarding the subject area *Hearing* and boxplots of the *50%-SRT* are shown.
HA-NU = hearing aid non-user; HA-U = hearing aid user; SRT = speech reception threshold.

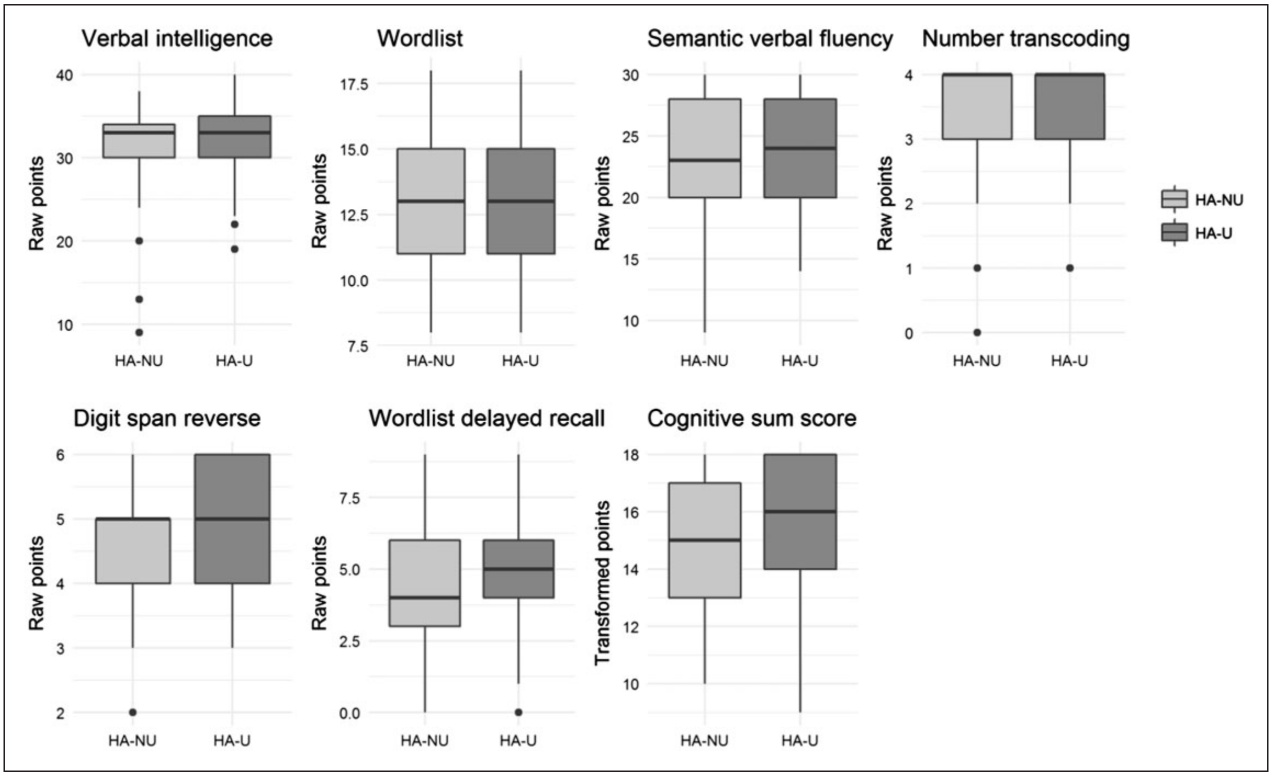

Figure 3. Cognitive performance of HA-NU and HA-U. The boxplots show the distributions of the seven cognitive test measures *Verbal intelligence*, *Wordlist*, *Semantic verbal fluency*, *Number transcoding*, *Digit span reverse*, *Wordlist delayed recall*, and *Cognitive sum score*. HA-NU = hearing aid non-user; HA-U = hearing aid user.

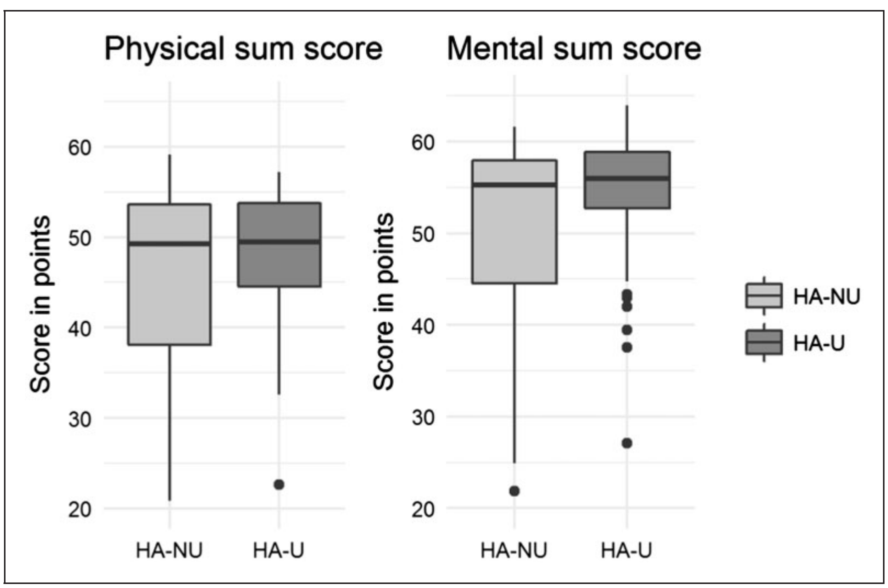

Figure 4. Health status of HA-NU and HA-U. Distributions of the *Physical* and *Mental sum score* of the SF-12 are shown. HA-NU = hearing aid non-user; HA-U = hearing aid user.

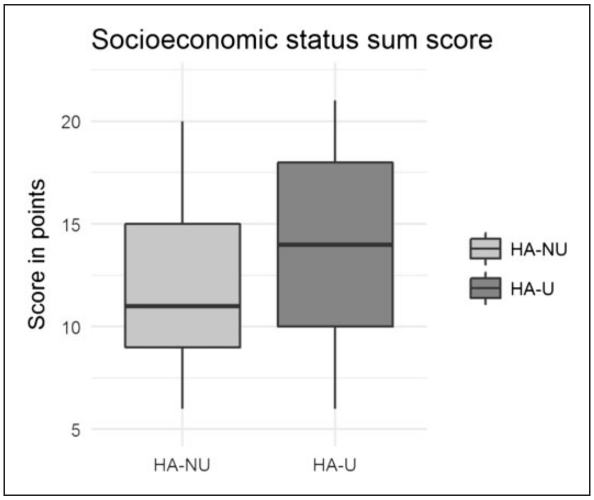

Figure 5. Socioeconomic status of HA-NU and HA-U. Figure 5 shows distributions of the *Socioeconomic status sum score*.
HA-NU = hearing aid non-user; HA-U = hearing aid user.

(percentages) across the single self-reports *School graduation*, *Professional degree*, *Main professional occupation*, and *Net income per household*, yielding the socioeconomic status, are shown. For the variable, *Socioeconomic status sum score* ES was 0.46.

Technology commitment and usage habits of media devices. Finally, combined results assessing the *Technology commitment and the usage habits of media devices* are shown in Figure 6. Hearing aid non-users seemed to be less competent with regard to new technical products, and seemed to hardly accept new technological developments. Furthermore, they seemed to indicate lower (i.e., poorer) technology control than hearing aid users. Lastly, HA-NU reported using media devices on average less frequently than their aided peers. The more detailed group comparisons based on relative frequencies across the single questions assessing the technology competence, acceptance, control, and the usage habits of media devices (such as smart-, mobile or fixed phones,

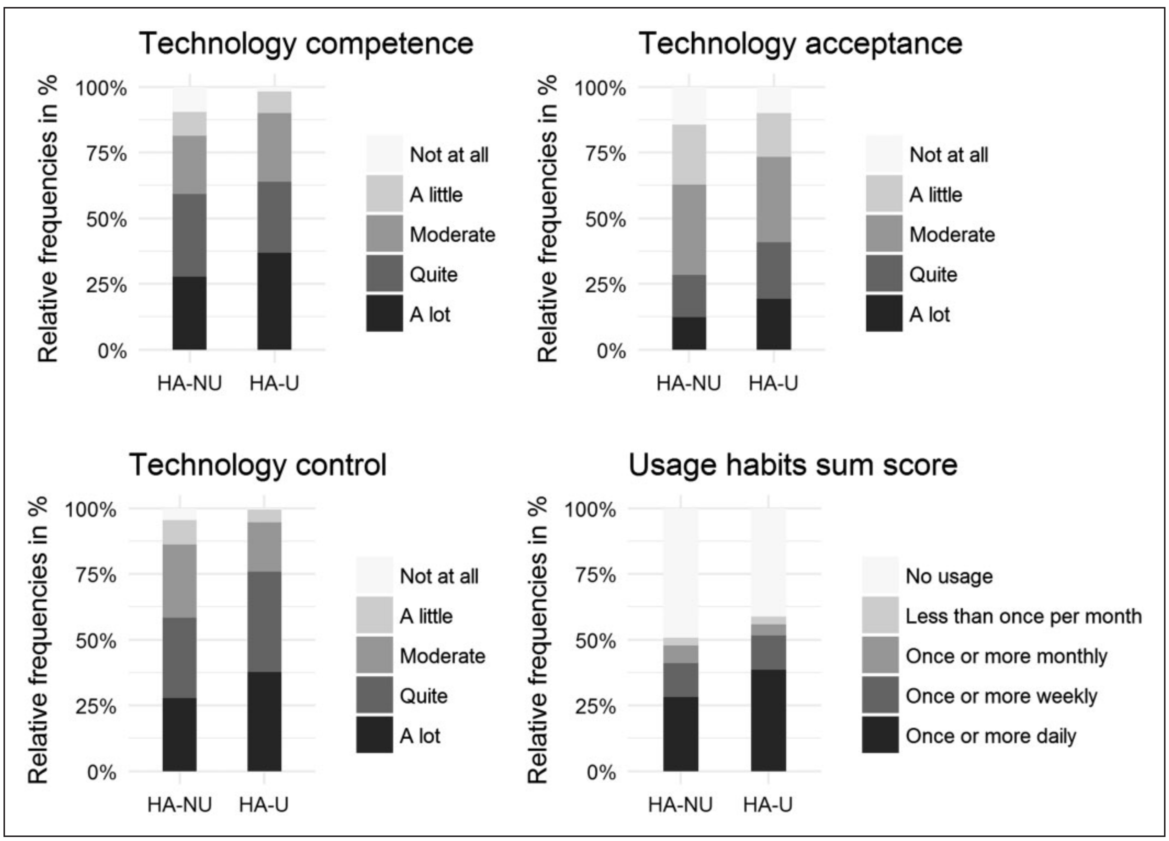

Figure 6. Frequency distributions of the measures assessing the *Technology commitment and usage habits of media devices* among HA-NU and HA-U. Relative frequency distributions of the measures *Technology competence*, *Technology acceptance*, *Technology control*, and *Usage habits sum score* are shown.
HA-NU = hearing aid non-user; HA-U = hearing aid user.

PCs, tablets, MP3 player, the Internet or E-mails) are visualized in Supplementary Figure S4 and in Supplementary Figure S5. ES for the variables *Technology commitment mean score* and *Usage habits sum score* were 0.45 each.

Statistical Analysis of HA-NU and HA-U

In order to identify relevant predictors for hearing aid use versus non-use, a stepwise logistic regression approach was performed. From the test measures *50%-SRT*, *Subjective hearing problems in quiet*, *Verbal intelligence*, *Cognitive sum score*, *Health mean score*, *Socioeconomic status sum score*, *Technology commitment mean score*, and *Usage habits sum score*, the stepwise selection algorithm selected five measures repeatedly as predictor variables across the 20 logistic regression approaches: In all of the 20 models, the variables *Subjective hearing problems in quiet* and *Health mean score* were selected as regressors suggesting that these are the most important predictor variables for being a hearing aid user according to AIC. The *Socioeconomic status sum score* was selected in nine regression approaches, followed by the variable *Technology commitment mean score* (selected 2 times) and *Verbal intelligence* (1 time).

Odds ratios of the five predictor variables that were selected by stepAIC among the 20 regression approaches as well as the respective 95% CI are shown in Table 1. For $\alpha = .05$, the four predictors *Subjective hearing problems in quiet*, *Health mean score*, *Socioeconomic status sum score*, and *Technology commitment mean score*, showed a significant influence on being a HA-U (vs. being a HA-NU). For example, for the former, the odds ratio can be read as follows: For a one unit increase in the *Technology commitment mean score*, the odds of using a hearing aid (vs. not) increases by the factor 1.35.

Mean null deviance was 125.6 and the mean deviance according to the 20 regression models was 94.7, indicating an improvement (in the sense of the goodness-of-fit statistic) by adding the respective predictor variables to the logistic regression models.

Table 1. Odds Ratios for Being a HA-U (vs. Being a HA-NU) From the Multivariable Logistic Regression Model.

Predictor variables	Odds ratio [95% CI]
Hearing	
Subjective hearing problems in quiet	
Medium-to-very strong	10.54 [8.29, 13.49]
No-to-very slight	Ref.
Cognition	
Verbal intelligence	1.00 [0.97, 1.03]
Health status	
Health mean score	1.11 [1.08, 1.13]
Socioeconomic status	
Socioeconomic status sum score	1.08 [1.04, 1.11]
Technology commitment and usage habits of media devices	
Technology commitment mean score	1.35 [1.13, 1.61]

Note. Odds ratios and 95% confidence intervals of the five predictor variables are shown. Predictor variables are ordered and grouped according to the subject areas *Hearing, Cognition, Health status, Socioeconomic status*, and *Technology commitment and usage habits of media devices*.

Sensitivity Analysis for Matching

Finally, to test the role of possible confounds due to group differences in the degree of hearing loss, age, and sex, the descriptive comparisons and the logistic regression approach were repeated, now using the dataset with all 221 potential hearing aid non-users and users — not being matched on the variables *PTA*, *Age*, and *Sex*. HA-NU showed less severe hearing problems than HA-U, no group differences were found in most of the cognitive measures, and boxplots of the *Physical* and *Mental sum score* revealed a similar picture as in the case of matching. Moreover, 25%- and 75%-quantiles of the socioeconomic status sum score as well as the arithmetic mean were lower in HA-NU than in HA-U and, as in the case of matching, HA-NU showed less technology commitment and less usage habits of media devices than HA-U. In the logistic regression approach, the three measures *50%-SRT*, *Subjective hearing problems in quiet*, and *Health mean score* were selected by the stepwise selection algorithm as most important predictor variables, and all three predictors showed a significant influence on being a HA-U versus being a HA-NU.

Discussion

The aim of this study was to compare unaided hearing aid candidates with a mild-to-moderate hearing loss (i.e., hearing aid non-owners who are inexperienced in using hearing aids, but who would already benefit from them) with their aided counterparts, in order to identify differences that might be associated with the low hearing aid uptake rate. We investigated hearing aid non-users without any hearing aid experience (HA-NU) and hearing aid users (HA-U) that were matched multiple times for the degree of hearing loss, age, and sex. First, we explored whether there were any differences between HA-NU and HA-U with respect to the frequency distributions of 65 auditory and non-auditory test measures belonging to the six subject areas *Matching*, *Hearing*, *Cognition*, *Health status*, *Socioeconomic status*, and *Technology commitment and usage habits of media devices*. In a second step, we performed a stepwise logistic regression approach to identify relevant measures predicting whether an individual is a hearing aid user or a non-user. Eight summarizing test scores that were representative for the aforementioned subject areas served as potential predictor variables (*50%-SRT*, *Subjective hearing problems in quiet*, *Verbal intelligence*, *Cognitive sum score*, *Health mean score*, *Socioeconomic status sum score*, *Technology commitment mean score*, *Usage habits sum score*). Finally, a sensitivity analysis for balancing HA-NU and HA-U with respect to the degree of hearing loss, age, and sex was conducted. We therefore repeated descriptive comparisons and the logistic regression approach by using unmatched samples of HA-NU ($n = 72$) and HA-U ($n = 139$).

Summing up, we found the following: Despite matching on *PTA*, HA-NU reported lower hearing problems in self-reports. Furthermore, group differences were found in technology commitment, the socioeconomic status, and in some of the test measures assessing cognitive performance, such that HA-NU showed lower (i.e., worse) values than HA-U. The health status seemed slightly poorer in HA-NU than in HA-U. The most important predictors for using hearing aids were self-reported hearing performance, the technology commitment, as well as the socioeconomic and the health status. While our findings with respect to self-reported hearing performance relate to previous research, the role of technology commitment has rarely been examined so far, and results on socioeconomic status have been contradictory.

Matching

Previous studies found a direct relation between the degree of hearing loss and hearing aid uptake (for reviews see Jenstad & Moon, 2011; Knudsen et al., 2010; Meyer & Hickson, 2012). As we wanted to investigate, among others, associations between cognitive measures and hearing aid use, which might be mediated by a repeatedly reported interaction between the degree of hearing loss and cognition in older adults (Lin et al., 2011, 2013; Gussekloo, de Craen, Oduber, van Boxtel, & Westendorp, 2005; Uhlmann, Larson, Rees, Koepsell, & Duckert, 1989), we balanced the two groups of elderly hearing aid non-users and users with respect to the degree of hearing loss to control for possible confounding effects.

Knudsen et al. (2010) reported that sex and age showed no direct influence on neither help-seeking, nor hearing aid uptake or hearing aid use. However, sex and age differences may affect group differences in other measures of our test battery, such as those assessing the health status, or the technology commitment. Sex differences, for example, are known in general health (Verbrugge, 1985), and women tend to use medical care more frequently than men (Green & Pope, 1999). Recently, Pronk et al. (2017) found that predictors of entering a hearing aid evolution period (i.e., a 2-month trial period in the Netherlands which is a standard part of the purchase process of hearing aids that is free of cost and offered to every client before having to decide to buy the device or not) differ as a function of sex, such that greater severity of hearing impairment and hearing aid stigma were predictors in women but not in men. Furthermore, age has an undisputable effect on the cognitive performance.

When considering HA-NU and HA-U not being matched on the variables *PTA*, *Age* and *Sex*, descriptive comparisons yielded similar results as in the case of matching — except for the measures assessing hearing performance. This was not unexpected considering the group differences in *PTA* before matching. Likewise, in the logistic regression approach, two measures assessing hearing performance were among the three most important predictor variables for using hearing aids. In summary, without balancing both groups, particularly with respect to *PTA*, results were dominated by group differences in measures assessing hearing performance. Lastly, due to additional matching on *Age* and *Sex*, we controlled for further possible confounding effects discussed above.

Hearing

Interestingly, although we matched for the degree of hearing loss using the test measure *PTA*, self-reported hearing problems revealed differences in their frequency distributions. Hearing aid users seem to perceive their hearing problems in noise and in quiet as more severe than their unaided matching partners. Note that 10.9% of the HA-NU were not even aware of their hearing difficulties. Self-reported hearing problems were, beyond that, among the most important variables predicting the use versus non-use of hearing aids.

Our findings are consistent with Knudsen et al. (2010) who concluded — based on reported studies that were conducted in different states of the United States, Great Britain, and the Netherlands — that self-reported hearing problems positively affect help seeking, hearing aid uptake, hearing aid use, and satisfaction with hearing aids. Given this accumulating evidence resulting from diverse countries, it is reasonable to assume that self-reported hearing problems might be a relevant factor influencing hearing aid use and uptake worldwide. Furthermore, the results are of interest in the light of the study by Humes et al. (2003) who investigated group differences on a variety of measures for elderly hearing aid candidates. They observed that, despite matching for sex, age, and hearing loss, individuals who declined hearing support were less aware of a communication problem due to hearing impairment and, accordingly, experienced less communication-related stress than individuals who purchased hearing aids. Humes and colleagues speculated that hearing aid non-users tended to deny the existence of their communication problem. This points to differences in personality and might also be relevant in the context of previous studies that have investigated associations between personal factors and hearing aid use (Garstecki & Erler, 1998; Helvik, Wennberg, Jacobsen, & Hallberg, 2008; Saunders, Frederick, Silverman, Nielsen, & Laplante-Lévesque, 2016). Cox et al. (2005) found systematic differences in some personality characteristics between hearing aid seekers and the general population, such that individuals who aim to use hearing aids tended to be more pragmatic and routine-oriented, as well as more powerful in dealing with problems, when compared with the typical adult. In our study, hearing aid users reported being more demanding on the sound quality of audio devices than non-users. It is possible that personal differences in how demanding individuals are with regard to the sound quality represent another relevant factor in this context.

Finally, one can speculate that someone who suffers from hearing loss in the mild-to-moderate range indeed is impaired but most likely not affected by a severe disability, which might be one explanation for the proportion of unawareness in HA-NU. At the same time, general differences between felt and measured needs are conceivable. Whether the observed differences in subjective hearing problems arose from the experience of the HA-U in both situations, with and without amplification, is not clear, however.

Technology Commitment and Usage Habits of Media Devices

We found significant associations between the use of hearing aids and technical products, such that hearing aid non-users showed lower (i.e., worse) technology commitment and indicated a lower use of media devices than their aided counterparts, and we assume that similar results would be found in other developed countries. Our findings are in line with Gonsalves and Pichora-Fuller (2008) who related hearing loss and the use of hearing aids to older adults' extent to use information and communication technologies. They investigated 135 elderly, Canadian individuals of whom 82 people were individuals with normal hearing and the remaining 53 were individuals with corrected ($n = 28$) and uncorrected ($n = 25$) hearing loss, and found that the latter (hearing aid non-users) did not use these technologies as much as individuals with corrected hearing loss (hearing aid users). In contrast to our study, however, Gonsalves and Pichora-Fuller did not control for possible confounding effects, such as age or sex, nor did they take further factors into account, such as the socioeconomic status.

Stieglitz Ham and colleagues also examined associations between technology and hearing aid use in the elderly (Stieglitz Ham et al., 2014). They investigated four groups of Australian individuals with hearing impairment: (1) individuals who had not sought help yet ($n = 49$), (2) individuals who had sought help but chose not to adopt hearing aids ($n = 62$), (3) hearing aid owners who were unsuccessfully, and (4) successfully using them ($n = 61$, and $n = 79$, respectively), which were — in contrast to our study — not matched regarding the degree of hearing impairment, sex, and age. First, they found significant group effects for two scores assessing how often participants used (a) everyday (e.g., DVD player) and (b) advanced (e.g., Bluetooth) technology. After including demographic and socioeconomic covariates, however, no significant group differences were found anymore, whereof the authors concluded that technology use is not an explaining factor for the hearing aid uptake and use in the elderly. Moreover, they found an association between technology use and the covariates *Age*, *Sex*, and *Living arrangements*. We speculate, however, whether these three covariates served as confounder variables in their analyses that resulted in no group effects. Maybe, in case of balancing the groups with respect to the variables *Age*, *Sex* and *Living arrangements*, group effects could be found again for the two technology scores. In our study, HA-U and HA-NU showed quite similar living arrangements: 22.2% of the HA-U and 21.9% of the HA-NU lived in a one person household, whereat the remaining individuals indicated that they live together with one or two other persons.

Socioeconomic Status

In our study, the *Socioeconomic status sum score* was significantly related to the use of hearing aids, such that HA-U were more likely to have a higher socioeconomic status than their aided matching partners. In the light of prior studies, mixed results have been found regarding the role of the socioeconomic status: The review by Knudsen et al. (2010) reported either a positive or no association between the socioeconomic status and the uptake and use of hearing aids. In this context, however, it was not accounted for the costs of hearing aids. Furthermore, Fischer et al. (2011) found an association between hearing aid acquisition and education. Their study was conducted in the United States, where hearing aids are not generally covered by health insurance. Results of another recent study conducted in the United States indicate higher prevalence of unaided hearing loss in elderly individuals with low income than in elderly individuals with high income (Mamo, Nieman, & Lin, 2016). In contrast, the results of Benova, Grundy, and Ploubidis (2014) suggest that hearing aid acquisition is not related to the socioeconomic status covering the four indicators education, occupation, income, and wealth. They conducted their study in England, where hearing aids are available free of charge through the National Health Service. As education is related to income, this raises the question whether the costs of hearing aids could be a mediating factor for these cross-cultural differences in education or the socioeconomic status, respectively. Manchaiah et al. (2015) recently investigated the social representation of hearing aids in India, Iran, Portugal, and the United Kingdom, and reported that the category cost was one of the most common categories being related to hearing aids across all four countries. In addition, Garstecki and Erler (1998) reported that concerns about costs were more prevalent in non-adherents compared to adherents (i.e., individuals who decided against or for acquiring and using hearing aids, respectively). This is in line with Gopinath et al. (2011) who found that high costs were one of the key reasons for not using hearing devices. Likewise, Meis and Gabriel (2006) confirmed that the price is one main barrier in hearing aid provisioning in Germany. This is of importance since wealthier people (and therefore usually people with a higher socioeconomic status) are generally better able to bear higher costs than poorer ones, and our results suggest that HA-U do have a higher socioeconomic status than HA-NU in Germany. Thus, it is possible that this finding is mediated by the factor cost, and that wealthier people are more likely to afford hearing aid provisioning.

In Germany, health insurance is obligatory. The majority has statutory health insurance (about 85%), and only 11 % are enrolled in a private one (Institute for Quality and Efficiency in Health Care, 2015). Employees with an annual income below a certain threshold (approximately 58,000 EUR in 2017; Bundesregierung Deutschland, 2016) are members of a statutory health insurance. People with higher incomes as well as civil servants and self-employed people are allowed to choose between private and statutory health insurance providers. As physicians get higher reimbursement for private insurers, this group may obtain a better medical treatment probably resulting in a better health status in private versus statutory insurers (Stauder & Kossow, 2017). With regard to hearing support, private health insurances usually bear costs for hearing aids in the mid-class price segment. In contrast, the fixed amount for a hearing device in statutory health insurances has been doubled in November 2013 to 785 EUR (GKV-Spitzenverband, 2013). Nevertheless, Braun et al. (2015) reported that about 40% of 320 members of one statutory health insurance, who received hearing aids after November 2013, payed an own contribution of 1,000 EUR and more for their hearing aids. Thus, it is possible that Germans with a higher socioeconomic status are better able to bear the high amount of own payments for hearing devices or are members of private health insurances with possibly better medical treatment.

Health Status

In our descriptive analysis, we found that HA-NU reported on average slightly worse health status in comparison to their aided peers, which was confirmed by the logistic regression analysis where the predictor variable *Health mean score* showed significant influence on being a HA-U (vs. not). This result is in line with Öberg et al. (2012) who found an association between health status and ownership, benefit, and use of hearing aids in a Swedish study. Hearing aid non-users had the worst scores for general and mental health and indicated the highest scores for number of diseases. The authors speculated that these individuals are either not yet treated with hearing aids due to their overall poor health status and comorbidities, or that their aided peers showed a better health status as a consequence of successful rehabilitation. Both would be conceivable in other nations as well. In addition, poor health and medical disadvantage are generally accompanied by social disadvantage, also in developed countries such as Germany (Robert Koch Institut, 2015). In the light of this study, the result that HA-NU showed a lower socioeconomic status than HA-U might possibly be related to the group differences that were found with respect to the health status.

Cognition

Several studies have examined the relation between hearing aid use and cognitive performance. In this context, Kalluri and Humes (2012) reviewed previous data and found supporting evidence that hearing aids can affect immediate cognitive functions (i.e., $\leqslant 2$ months). In contrast, results of long-term (i.e., 3 months–2 years) effects of the treatment with hearing aids are equivocal, and respective data are limited. Recently, within the framework of a prospective 25-year longitudinal study, Amieva et al. (2015) found a positive relation between hearing aid use and cognitive performance in elderly individuals with hearing impairment. As their results further suggest that social isolation and depression mediate the link between hearing loss and cognitive decline, the authors speculate that hearing aid use may raise social activities, and thus, attenuate cognitive decline. Here, no conspicuous group differences between HA-NU and HA-U possibly being related to the use of hearing aids were found in any of the cognitive test measures. However, as the present study is an observational study with data collected at only one point in time per individual and test measure, we cannot draw any definitive conclusions here. Due to small sample sizes, for example, we decided not to distinguish between individuals with different durations of hearing loss and hearing aid experience. Thus, it is conceivable that other mediating factors, such as possible neural changes due to the use or non-use of hearing aids over time, may have affected our results. Furthermore, investigating individuals with more profound hearing difficulties might yield different results. Thus, in order to better understand possible causal relationships between hearing aid use and cognition, further long-term studies are needed.

Limitations and Strengths

Within the framework of the present cross-sectional design, drawing conclusions about the direction of the observed associations is not possible. Furthermore, generalizations based on the present findings should be made with caution because of possible confounding and bias due to the retrospective character. Despite the wide range of investigated measures, other factors that may influence the decision on acquiring a hearing aid, such as, for example, rehabilitation pathways or events experienced by individuals with hearing problems over the course of seeking help (cf. Knudsen et al., 2010), or stigma (for review see David & Werner, 2015), have not been included in this study. It is possible that HA-NU and HA-U who volunteer to participate in scientific studies are more socially engaged or more advantaged in physical and mental health, cognitive performance, technology commitment, or the socioeconomic status, than the broader population.

On the other hand, a strength of this study is that we used data from the large database of the Hörzentrum Oldenburg GmbH with 595 individuals who had completed a test battery consisting of a large set self-reports, as well as auditory and cognitive test measures. Due to this large sample size, it was possible to apply various exclusion criteria as well as the matching algorithm in order to minimize the risk of confounding effects.

Conclusion and Recommendation

Comparing hearing aid non-users with their aided counterparts across auditory and non-auditory test measures revealed differences in self-reported hearing problems suggesting that individuals with hearing loss, who perceive their hearing difficulties more strongly, are more likely to adopt hearing aids. This result confirms previous research. It is possible that individuals with mild-to-moderate hearing loss (i.e., 26 dB HL $\leqslant$ PTA $\leqslant$ 60 dB HL) who report less hearing problems are simply less aware of their difficulties. In that case, negative side effects of untreated hearing loss should be made more public in order to raise individuals' awareness of hearing problems and hence increase the hearing aid adoption rate. Moreover, we found that individuals with higher technology commitment, higher socioeconomic status, or better health tend to use hearing aids. Hitherto, the role of technology commitment and use has been rarely investigated and, to our knowledge, there exists no study examining the relation between the socioeconomic status and hearing aid use in Germany. It might be that augmenting the assistance in dealing with hearing aids would motivate those candidates with less technology commitment to adopt hearing devices. This could be done, for example, by audiologists, acousticians, or via online material (cf. Ferguson et al., 2016). Finally, supposing that the factor costs is a mediating factor for our results on the socioeconomic status, more financial support for acquiring hearing devices should be offered in countries where individuals with hearing impairment have to pay own contributions for hearing aids.

Author Contributions

MT conceptualized the research question, analyzed the data, interpreted the results, wrote the manuscript, and prepared the figures and tables. Data acquisition was conducted by the Hörzentrum Oldenburg GmbH under the responsibility of KW. MM elaborated particularly questions regarding the technology commitment and the socioeconomic status of the questionnaires of the test battery. AG, MM, KW, and HC critically reviewed and significantly contributed to the manuscript. All authors approved the final version of the manuscript for publication. All authors agree to be accountable for all aspects of the work and in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

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Note

1. All variables entering the analysis are described in the Supplementary Table S1 and are written in italic letters.

Supplemental Material

Supplemental material for this article is available online.

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