

On the relationship between functional hearing and depression

Gitte Keidser^a, Mark Seeto^a, Mary Rudner^b, Staffan Hygge^c, Jerker Rönnerberg^b

^aNational Acoustic Laboratories, Sydney, Australia

^bLinnaeus Centre HEAD, Swedish Institute for Disability Research, Department of Behavioural Sciences and Learning, Linköping University, Sweden

^cEnvironmental Psychology, Faculty of Engineering and Sustainable Development, University of Gävle, Sweden

Address for correspondence:

Gitte Keidser, National Acoustic Laboratories, Australian Hearing Hub, 16 University Avenue, Macquarie University, NSW 2109, Australia

Email: gitte.keidser@nal.gov.au

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Abbreviations: b = non-standardised regression coefficient; BESRT_n: better ear speech reception threshold in noise; E = effect size; FH General: functional hearing in general; FH Noise: functional hearing in noise; GP: general practitioner; HA: hearing aid; SNR: signal-to-noise ratio; SRT_n: speech reception threshold in noise; UK: United Kingdom

Abstract

Objective: To establish the effect of self-rated and measured functional hearing on depression, taking age and gender into account. Additionally, the study investigates if hearing aid usage mitigates the effect, and if other physical health problems and social engagement confound it.

Design: Cross-sectional data from the UK Biobank resource, including subjective and behavioural measures of functional hearing and multifactorial measures of depressive episodes and symptoms, were accessed and analysed using multi-regression analyses.

Study sample: Over 100,000 community-dwelling 39-70 years old volunteers.

Results: Irrespective of measurement method, poor functional hearing was significantly ($p < 0.001$) associated with higher levels of depressive episodes (≤ 0.16 factor scores) and depressive symptoms (≤ 0.30 factor scores) when controlling for age and gender.

Associations were stronger for subjective reports, for depressive symptoms, and the younger participants. Females generally reported higher levels of depression. Hearing aid usage did not show a mitigating effect on the associations. Other physical health problems particularly partially confounded the effects.

Conclusion: Data support an association between functional hearing and depression that is stronger in the younger participants (40-49 years old) and for milder depression. The association was not alleviated by hearing-aid usage, but was partially confounded by other physical health problems.

It is well-established that there is stigma attached to hearing impairment and the use of hearing devices, which can act as a barrier to accessing audiological services and influence to what extent hearing devices are used (Gagne et al., 2009, Wallhagen, 2010). This is problematic as untreated hearing loss has been associated with a decreased health-related quality of life (Appollonio et al., 1996, Chia et al., 2007, Dalton et al., 2003, Strawbridge et al., 2000). The mechanisms for the association are currently not well-understood as randomised controlled trials to address these questions are considered unethical (Dillon, 2012). In the absence of such trials, consistent evidence-based data on associations between untreated hearing loss and health-related quality of life conditions obtained from cross-sectional and longitudinal studies are relied upon to potentially encourage more hearing-impaired people to seek help and to accept rehabilitation with hearing aids.

Quality of life is affected when mental health suffers. Hearing status has been found to be moderately or strongly associated with mental health in some studies (Carabellese et al., 1993, Dalton et al., 2003, Kramer et al., 2002, Saito et al., 2010, Strawbridge et al., 2000, Huang et al., 2010), while in other studies no association has been found (Chou, 2008, Jagger et al., 2005, Jones et al., 1984). This discrepancy may partly be explained by how hearing status and mental health were measured. For example, in one cross-sectional study (Dalton et al., 2003), degree of hearing loss was measured through pure-tone audiometry, and the effects of the hearing loss were measured through self-reports of hearing difficulty and hearing handicap. Although the three hearing status measures were significantly correlated with each other, and all showed a significant association with mental health, self-reported hearing handicap was the strongest predictor. Similar observations were made by Tambs (2004) and Saito et al. (2010), suggesting that self-reported hearing difficulties are more closely associated with mental health than hearing loss measured by pure-tone audiometry.

The opposite pattern has also been demonstrated (Chia et al., 2007, Lee et al., 2010). In the study by Chia et al. (2007), measured bilateral hearing loss was associated with mental health, while self-reported hearing status, based on the response to a single direct question: “Do you feel you have hearing loss?” was not. The difference in findings between this and the above studies, where participants were asked about their communication difficulties, could be due to how the questions presented to participants were worded. Given the stigma attached to hearing loss, it is possible that some people are less willing to identify themselves with the term ‘hearing loss’ or ‘hearing impairment’ but are more forthcoming in answering questions that address specific communication problems. It is not clear how information about subjective hearing status was obtained in Lee et al (2010).

In the investigations of the relation between hearing status and mental health, many and varied measurements of mental health have also been introduced that primarily relied on self-reports with frequent references made to depression. Mental health refers to an individual’s ability to negotiate the daily challenges and social interactions of life without experiencing undue emotional or behavioural incapacity (Commonwealth Department of Health and Aged Care, 1999), and is determined by such factors as psychosocial adjustment, life satisfaction, and self-actualisation (Hackney and Sander, 2003). Thus the spectrum of mental health is broad. Even depression, which is considered the most commonly reported mental health problem (CDHAC, 1999), needs further classification as it can be diagnosed along a continuum from mild depressive symptoms to clinical depression (4th ed., text rev.; DSM–IV–TR; American Psychiatric Association [APA], 2000). According to Mulsant & Ganguli (1999), the prevalence of depressive symptoms is much higher than the prevalence of clinical depression, and at least one study has demonstrated that people with sensory impairment had

significantly more depressive symptoms, but were not significantly more clinically depressed, than people with no sensory impairment (Lupsakko et al., 2002). Consequently, in order to determine the full impact of hearing status on, for example, depression, it is desirable to look at a broad spectrum of the continuum from mild depressive symptoms to major depression.

Together with the selected measures of hearing status and mental health, the age group targeted could also be a contributing factor to the inconsistent findings. The effect of hearing status on mental health may change across the lifespan. Younger and middle-aged people may lead a more social lifestyle; hence experiencing communication difficulties more often, than older people, and are likely to have different communication obligations, such as those experienced in the workplace (Nachtegaal et al., 2009). Epidemiology studies often target older adults over 60 years of age. A few recent cross-sectional studies have included young and middle-aged participants. In one such study (Tambs, 2004), the associations between pure-tone thresholds and anxiety, depression, self-esteem, and well-being were investigated separately for men and women between 20 and 44 years, between 45 and 64 years, and over 65 years of age. Overall, the study found that the associations were stronger among the young and middle-aged participants with more severe hearing problems than among the elderly. Similarly, Nachtegaal et al. (2009) found that hearing difficulty was associated with poor psychosocial health in the younger age groups but not in the elderly population (those between 60 and 70 years old). Specifically, depression was significantly associated with hearing problems only among participants in their 40s. It could be argued that any adverse effect of hearing in younger and middle-aged people is of greater concern due to the potential longer term economic impact it may have on society (Danermark and Gellerstedt, 2004). Further, in older populations, depression has often been more significantly associated with such parameters as visual impairment (Carabellese et al., 1993), chronic physical diseases

(e.g. heart diseases, cancer, and diabetes) (Chou, 2008), and physical disability (Jones et al., 1984) than with hearing impairment.

More generally, depression has been found to be strongly linked to poorly rated health and increasing number of physical symptoms experienced (Kroenke et al., 1994, Beekman et al., 1997, Mulsant et al., 1997). Consequently, considering other physical health problems, especially chronic physical diseases, as a confounding effect on any association between hearing difficulty and mental health is of interest. Likewise, social engagement is a contender for a confounding factor. Studies have suggested that hearing problems lead to reduced social functioning (Strawbridge et al., 2000, Weinstein and Ventry, 1982), a factor that is also linked to depression in the general population (Alpass and Neville, 2003, Glass et al., 2006).

This study uses a resource known as the UK Biobank, which offers epidemiology data on more than 500,000 people aged between 40 and 70 years (Allen, 2012), to examine the association between hearing status and depression in a community-dwelling population and its interaction with age and gender. Specifically, the resource has collected various measures of mental health that are primarily associated with depression; ranging from mood symptoms and satisfaction with health, family situation, and finances to frequency and duration of episodes of depression and mania. This enables potential conceptually different continuous variables on depression to be formed that cover the broad spectrum and states of this factor. The resource further focuses on functional hearing rather than loss of sensitivity as measured with pure-tone audiometry, and provides both behavioural and subjective measures of functional hearing in noise. Thus, the UK Biobank data enable an investigation into the

association between both behavioural and subjective measures of functional hearing and multi-factorial measures of depression, and to compare their strength.

The UK Biobank data also provide information about hearing aid usage. A few studies have suggested that treatment with hearing aids can improve social integration and quality of life (and hence reduce mental health symptoms) in people with hearing disability (Appollonio et al., 1996, Lee et al., 2010, Mulrow et al., 1992, Kochkin and Rogan, 2000, Mener et al., 2013). The evidence is currently not strong. For decades, it has been demonstrated that fewer than 25% of people with a measurable hearing loss are treated with hearing aids (Jones et al., 1984, Nachtegaal et al., 2009, Hartley et al., 2010, Kochkin, 2001). If it can be shown that hearing impairment is associated with depression in some form, and hearing aid usage can alleviate symptoms associated with depression, this may encourage more hearing-impaired people to seek rehabilitation and to use hearing aids.

Using the UK Biobank data, the aims of this study were to:

- 1) Establish the association between measured and self-reported functional hearing and multifactorial measures of depression when controlling for age and gender;
- 2) Investigate whether hearing aid usage has a mitigating effect on any significant associations between functional hearing (measured or self-reported) and the depression factors;
- 3) Investigate whether other physical health problems and social engagement may confound a significant association between functional hearing (measured or self-reported) and the depression factors.

Methodology

Sample and protocol

From the UK Biobank resource, data were obtained on 497,984 individuals. From this cohort, participants born outside of the UK and the Republic of Ireland were excluded as unknown language and cultural differences may affect their mental health (Pumariega et al., 2005). Of the remaining population, 101,099 participants had completed testing on hearing and answered multiple questions about their mental health. In this sample, the female to male ratio was 51:49. Ages ranged from 39 to 70 years, with a mean of 56.8 years. On these parameters the study sample was representative of the entire UK Biobank sample (54% females to 46% males; mean age = 56.5 years), with the gender distribution matching that of the 2001 UK census according to Dawes et al. (2014).

All measures presented in this study were obtained in a self-administered manner via a computer, using a touchscreen to collect responses to questionnaires and the hearing test.

Hearing measures

Functional hearing was measured subjectively and behaviourally. The subjective measures consisted of two direct questions about difficulty hearing: 1) “Do you have any difficulty hearing?” and 2) “Do you find it difficult to follow a conversation if there is background noise (such as TV, radio, children playing)?” with the response options yes/no. The two measures are referred to as reported functional hearing in general (FH General) and reported functional hearing in noise (FH Noise) in the following analyses. Of the study sample, 27% responded in the affirmative to question one and 34% to question two, with 22% agreeing with both questions. These percentages are representative of the entire UK Biobank sample (25% and 37% responding yes to questions one and two, respectively). Note that more

participants agreed to have difficulty conversing in noise than agreed to have difficulty hearing in general.

The behavioural measure of functional hearing consisted of a digit triplets test presented in a rushing noise (Smits et al., 2004). According to Smits et al. (2004), performance on the digit triplets test is significantly correlated with pure-tone thresholds averaged across 0.5, 1.0, 2.0, and 4.0 kHz. The correlation of 0.77 suggests that about 60% of the performance on the digit triplets test is explained by standardised audiometric data. The remaining variation in performance is likely explained by differences in the psychoacoustic ability of the listener, which strongly influence the ability to recognise speech in noise (Plomp, 1978). The digit triplets test thus qualifies as a behavioural measure of the participants' functional hearing in noise. The test was presented to participants unaided under headphones. Each ear was tested separately, with the volume of the speech set for each ear to the individual's most comfortable level for that ear. After the presentation of each triplet, participants entered the three digits heard in the same serial order (forced choice) on a number pad shown on the touchscreen. If the triplet was correctly identified, the noise level increased; otherwise the noise level decreased. Fifteen triplets were presented, with the last eight presentations constituting the assessment. The resulting speech reception threshold in noise (SRT_n) was the signal-to-noise ratio (SNR) arrived at after the final presentation. The SNR could vary between -12 and +8 dB. A best ear SRT_n (BESRT_n) was obtained as the behavioural measure of functional hearing for each participant and used for further analysis. For those who completed the test on only one ear, it was assumed that this was the better ear. Using the cut-off SNRs presented in Dawes et al. (2014), which were based on data from Smits et al., (2004) and Vlaming et al., (2001), 89.7%, 9.0%, and 1.3% of participants are considered to have hearing within a 'normal' (BESRT_n < -5.5 dB), 'insufficient' (BESRT_n from -5.5 to -

3.5 dB, incl.), and ‘poor’ (BESRTn > -3.5 dB) range, respectively. This distribution is in agreement with the distribution for the entire UK Biobank resource sample (Dawes et al., 2014). The total of 10.3% performing outside the normal range approaches the 14% of the slightly older cohort (55-74 year olds) in the UK who have a bilateral hearing impairment of at least 35 dB HL (Davis et al., 2007).

Hearing aid usage measure

All but 19 participants provided a yes/no response to a question on hearing aid (HA) usage: “Do you use a hearing aid most of the time?” Only 2.7% of the study sample reported using a HA. This proportion is a fraction lower than the 3.0% seen in the entire UK Biobank sample, which corresponds to the reported hearing aid intervention rate of 3% among 55-74 year olds in the UK (Davis et al., 2007).

Mental health measures

Participants were asked a variety of questions related to their mental health. The set of questions did not together constitute a standardised questionnaire but covered a wide range of topics associated with depression. Some of these questions probed a similar topic and used the same response scale. For the sake of simplicity, these questions were consolidated to provide four constructs. The four constructs (described below) were together with five unconsolidated questions included in a principal factor analysis to identify conceptually different continuous variables on depression for use in further analyses (cf Table I).

Two of the four constructs were formed from twelve questions that constituted a subset of yes/no questions from the neuroticism scale of the Eysenck Personality Inventory (Eysenck & Eysenck, 1976), a frequently used research tool to assess personality traits in the categories of

neuroticism/stability, extraversion/introversion, and psychoticism/socialisation. According to a clinimetric analysis by Bech et al. (2012), subsets of items in the neuroticism scale relate to depression and anxiety symptoms. Among the 12 questions used by UK Biobank, six relate to depression symptoms, (mood swings, feeling miserable, feeling fed-up, feeling guilty, suffering from ‘nerves’, feeling lonely) while another six relate to anxiety symptoms (feeling irritable, easily hurt, feeling nervous, feeling worried, feeling tense, worrying too long after an embarrassing experience). Answers to each of these sets of questions were consequently consolidated into two constructs referred to as ‘*neuroticism depression*’ and ‘*neuroticism anxiety*’, respectively, with scores corresponding to the number of symptoms experienced.

A third construct was formed from six questions asking for rated happiness with job, health, family situation, friendship situation, finances, and generally (extremely happy/very happy/moderately happy/moderately unhappy/very unhappy/extremely unhappy). An independent principal factor analysis using the multiple R^2 technique for extraction, confirmed that these six questions loaded on a single factor when using a cut-off eigenvalue of one. The six response options were assigned a score from 1 to 6 and the questions consolidated into a construct called ‘*satisfaction with life*’ by averaging the scores obtained across questions.

The fourth construct was a consolidation of four questions asking about frequency of feeling depressed, unenthusiastic/disinterested, tense/restless, and tired (not at all/several days/more than half the days/nearly every day). As above, a principal factor analysis confirmed that these four questions loaded on a single factor. The four response options were assigned a score from 1 to 4 and the questions consolidated into a construct called ‘*feeling down*’ by averaging the scores obtained across questions.

The remaining five, unconsolidated mental health questions asked participants, who agreed that they had ever felt depressed, unenthusiastic/disinterested, manic, or highly irritable/argumentative, for: longest period of depression (weeks), number of depression episodes (number), longest period of feeling unenthusiastic/disinterested (weeks), number of unenthusiastic/disinterested episodes (number), and longest period of feeling manic or irritable (at least two days but less than a week/ less than a week/a week or more). For simplicity, these five questions are henceforth referred to as '*duration of depression*', '*frequency of depression*', '*duration of unenthusiam*', '*frequency of unenthusiasm*', and '*duration of mania*'. The scales related to these questions were extended to include '0 weeks' or 'none', respectively, for those who had never felt depressed, unenthusiastic, or manic. The distribution of responses to these questions had a very high positive skew and kurtosis. Consequently, the four continuous variables were log transformed (natural logarithm of $x+1$), while the responses to the '*duration of mania*' question were trichotomised: zero days/at least two days/less than a week, or longer.

Factor analysis: The four constructs on 'neuroticism depression', 'neuroticism anxiety', 'life satisfaction' and 'feeling down' were together with the five transformed measures of duration and frequency of depression, unenthusiam, and mania included as independent variables in a principal factor analysis using the multiple R^2 technique for extraction and the varimax normalised strategy for rotation. The analysis revealed two factors with eigenvalues greater than one that explained 56% of variation in the data. The variables that loaded most highly on the first factor, all with weights above 0.80, were the four transformed measures related to duration and frequency of depression and enthusiasm, see Table I. The remaining variables, which included measures of mood and emotionality, loaded

more highly on the second factor with ‘neuroticism depression’ showing the highest weight (0.78), followed by ‘feeling down’ (0.69). Henceforth we refer to the two factors as ‘depressive episodes’ and ‘depressive symptoms’. The standardised factor scores for the two factors were used as dependent variables in further analyses.

Other measures

Other measures of interest obtained from the UK Biobank included demographic measures such as age and gender, and measures related to other physical health problems and social engagement, factors that potentially could confound any effects of functional hearing on the depression factors. Age was reported as years of age at the time of recruitment, while gender was dichotomised. Four measures provided information about chronic physical diseases and overall health. Participants were asked which of a range of specific diseases they had been diagnosed with. Based on the grouping of the questions in the questionnaire, replies were consolidated into three variables on the number of serious medical conditions (including diabetes, cancer, fractured bones, other serious medical conditions – scores from 0 to 4), number of vascular problems (including heart attack, angina, stroke, high blood pressure – scores from 0 to 4), and number of respiratory-related conditions (including blood clot, deep-vein thrombosis, bronchitis, emphysema, asthma, rhinitis, eczema, and allergy – scores from 0 to 8). As very few participants indicated more than two diagnoses in either problem area, the scores were for all three variables trichotomised to indicate no (0), one (1), or two or more (2) diagnoses. The participants also rated their overall health as excellent, good, fair, or poor. These responses were assigned a score from 1 (excellent) to 4 (poor).

Two measures provided information about social engagement. These measures were obtained through questions about frequency of friend/family visits, and number of social activities

engaged in (including sports club, pub/social club, religious group, adult education, and other group activity – scores from 0 to 5). As very few participants indicated that they were engaged in more than three activities, the scores for this variable were transformed into four categories, indicating no (0), one (1), two (2), or 3 or more (3) activities. The response options for the frequency of visits were: never or almost never/every few months/once a month/once a week/2-4 times a week/daily, which were assigned scores from 0 to 6.

Finally, the study sample also addressed questions about help seeking for mental health problems. Participants responded to two questions: “Have you ever seen a general practitioner (GP) for nerves, anxiety, tension, or depression?” and “Have you ever seen a psychiatrist for nerves, anxiety, tension, or depression?” The response options were: Yes/No/Do not know/Prefer not to answer. More than 99.7% of the study sample provided either a Yes or No reply to these questions, showing that 28% of participants had seen a GP and 9% a psychiatrist. These proportions are slightly lower than seen in the entire UK Biobank sample (34% and 12% seen a GP and a psychiatrist, respectively).

Data analyses

To establish the association between functional hearing and depression, six regression analyses were conducted using each of the two depression factor scores revealed by the factor analysis as dependent variables and each of the three measures of functional hearing as independent variables, controlling for the effects of age and gender. Interaction effects between hearing and age, and hearing and gender were included by entering the products of these variables as additional independent variables. The significance of all effects was determined with a multiple degree of freedom test. That is, a test of the overall effect of each variable (or interaction) was performed by testing the null hypothesis that the parameters

involving that variable (or interaction) are all equal to zero. Due to the large sample size, $p = 0.001$ was selected as the criterion for significance.

The effect of functional hearing is reported as the difference in estimated depression factor scores between ‘poor’ and ‘good’ hearers. Using regression equation (1) with the non-standardised regression coefficients (b) resulting from the relevant analysis, estimated depression factor scores were obtained for females (gender = 0) and males (gender = 1) aged 45, 55, and 65 years within each hearing group, and the effect of functional hearing calculated for the six combinations of gender and age. The reported estimated overall effect size (E) for functional hearing is the average of these six effects. For FH General and FH Noise, ‘poor’ and ‘good’ hearing equated to the presence (hearing = 1) and absence (hearing = 0) of self-reported hearing difficulty. For BESRTn, the effect sizes indicate the difference in factor score for a 10 dB change in SNR, which corresponds to the difference between performing roughly in the middle of the ‘poor’ (hearing = +1 dB SNR) and ‘normal’ (i.e. ‘good’) (hearing = -9 dB SNR) ranges. The 10-dB change in SNR was considered to be a reasonably conservative equivalent to reporting having or not having difficulty hearing for the purpose of comparing effect sizes between the behavioural and subjective functional hearing measures. Obtained in a similar way, reported estimated overall effect sizes for gender indicate the difference in depression factor scores between females (gender = 0) and males (gender = 1), and for age the reported overall effect sizes refer to the difference in depression factor scores for a 10-year change in age.

$$(1) \text{ Factor score} = b_0 + b_1 * \text{hearing} + b_2 * \text{gender} + b_3 * \text{age} + b_4 * \text{hearing} * \text{gender} + b_5 * \text{hearing} * \text{age}$$

To investigate whether HA usage had an impact on the association between functional hearing and the depression factors, the regression analyses were repeated, adding HA usage and the interaction between HA usage and hearing as independent variables. These two variables were added to equation (1), and following the procedure described above, the estimated overall effect sizes for HA usage are reported as the difference in the depression factor scores obtained for HA users (HA usage = 1) and non-users (HA usage = 0).

To examine the potential confounding effect of other physical health problems and social engagement on the relationship between functional hearing and the depression factors, these measures were included as independent variables in a regression analysis together with functional hearing while ignoring interaction effects.

Results

Before addressing the main research questions, some basic data on the hearing measures and depression factors are presented. According to a t-test for independent variables, those who responded positively to the questions on hearing difficulty produced a significantly higher BESRTn than those who gave a negative report ($t_{101097} > 49$; $p < 0.001$), although the differences in means between the two groups of 0.65 dB and 0.51 dB for FH General and FH Noise, respectively, were small. Reported HA users also produced a significantly higher BESRTn (by 2 dB) than non-users ($t_{101078} = 65.5$; $p < 0.001$). Figure 1 shows the percentage of participants within each of the three categories of BESRTn: normal, insufficient and poor (Dawes et al., 2014), who considered they had poor hearing (FH General, FH Noise), and who reported HA usage. Poor hearing and HA usage were reported more frequently as the performance on the behavioural test became poorer. However, 25-30% of those with behaviourally measured normal hearing reported poor hearing, and 25-30% of those with

behaviourally measured poor hearing reported good hearing. Those classified with insufficient hearing were almost equally divided between reporting poor and good hearing. Thus, there were some inconsistencies between the behavioural measure of functional hearing in noise and the perception of functional hearing. Generally, the measures of functional hearing correlated significantly ($p < 0.001$) and positively with age, but the correlations were small (Spearman $R = 0.14/0.15$ for FH General and FH Noise, respectively, and $r = 0.24$ for BESRTn).

For the depressive episodes factor, the mean factor score was -0.03 with a standard deviation of 0.95 factor scores. The mean factor score for depressive symptoms was -0.15 , with a standard deviation of 0.88 factor scores. A higher value indicates higher level of depression. Among the participants who produced factor scores within one standard deviation of the mean, 20% and 24% had sought professional help for depressive episodes and depressive symptoms, respectively. These percentages increased to 72% and 55% , respectively, when considering the population reporting mental health levels exceeding one standard deviation of the mean, supporting the notion that the severity of depression increased with increased factor scores. Further, whereas those who sought help, on average, produced depressive symptoms scores well within one standard deviation of the mean, those who had seen a psychiatrist showed average depressive episodes scores that exceeded one standard deviation of the mean while the average score for those who had seen a GP approached the one standard deviation value, see Figure 2. The observation that those reporting more severe levels of depressive episodes were more likely to have sought help than those who reported severe levels of depressive symptoms, suggest that the factor on depressive episodes taps into a more debilitating form of depression than the factor on depressive symptoms.

The association between functional hearing and depression

Table II summarises the significance levels for the association of the subjective and behavioural functional hearing measures and their interactions with age and gender with depressive episodes and depressive symptoms, and lists the estimated overall effect sizes of hearing. Using regression equation (1), Figure 3 shows the predicted interaction effects between functional hearing, gender, and age for the two depression factors. All three hearing measures showed a significant association ($p < 0.001$) with both depressive episodes and depressive symptoms after controlling for age and gender. In all cases the effect sizes were positive, suggesting that those with poor hearing generally reported higher levels of depressive episodes and symptoms than those with better hearing. The effect sizes, indicating the difference between 'poor' and 'good' hearing, were generally small ($E < 0.30$ factor scores), with the effect sizes for depressive episodes being consistently smaller than for depressive symptoms. For both depression factors, the greatest effect sizes were obtained for FH Noise ($E = 0.16$ factor scores for depressive episodes and $E = 0.30$ factor scores for depressive symptoms), which correspond to 0.17 and 0.34 of the standard deviation values for depressive episodes and depressive symptoms, respectively. Using Cohen's effect size classification, the estimated effect sizes obtained for depressive episodes were all small (< 0.2) while the estimated effect sizes for depressive symptoms were between small (0.2) and medium (0.5). The smallest effect size overall was observed for the prediction of depressive episodes by BESRTn ($E = 0.08$ factor scores per 10 dB SNR).

In all cases, age and gender also contributed significantly to the prediction of the depression factors ($p < 0.001$), with younger participants and females generally reporting higher levels of both depressive episodes and symptoms. While the estimated effect sizes of gender were greater for depressive episodes than for depressive symptoms, the reverse was observed for

age. The predictive effect of gender on depressive episodes slightly exceeded that of hearing ($E \approx -0.17$ factor scores; Std Err of $E = 0.006$ factor scores), whereas the predictive effect of a 10-year change in age on depressive symptoms was slightly lower than that of hearing ($E \approx -0.20$ factor scores; Std Err of $E = 0.003$ factor scores). There were significant interactions between hearing and age in all cases ($p < 0.001$) with the effect of functional hearing consistently being greater for the younger (in their 40s) than older (in their 60s) participants (by 0.13 factor scores, on average). The greatest difference in the effect of functional hearing between younger and older participants was seen in the prediction of depressive episodes by BESRTn, as in this case there was no effect of BESRTn among the older participants (-0.001 factor scores) while the estimated effect size among the younger participants was 0.17 factor scores (cf Figure 3). Functional hearing significantly interacted with gender in the prediction of depressive episodes when considering FH General and FH Noise ($p < 0.001$). In both cases the estimated effect of hearing was greater among females than males (by 0.05 factor scores, on average).

In summary, the findings suggest that both reported and measured functional hearing have independent and mostly small, but significant, associations with both depressive episodes and depressive symptoms, with those having poorer functional hearing reporting higher levels of depressive episodes and symptoms. The effect of functional hearing on the two dependent variables was predicted to be stronger among the younger test participants, and in some cases among females. While FH Noise and BESRTn (i.e. functional hearing in noise) showed the greatest predictive effect on depressive symptoms, FH General and FH Noise (i.e. reported functional hearing) better predicted depressive episodes.

Impact of hearing aid usage on the association between hearing and depression

Including HA usage and the interaction between functional hearing and HA usage in the regression analyses revealed non-significant effects of HA usage ($p > 0.02$) and the interaction term ($p > 0.06$) in all but one case (Table III). Only when controlling for BESRTn did HA usage significantly predict depressive symptoms ($p < 0.001$). The positive estimated effect size of 0.12 factor scores suggests that HA users, on average, reported higher levels of depressive symptoms than non-users. A closer inspection of data revealed that this effect is highly influenced by performances among the good hearers. The interaction effect in this case was nearing significance ($p = 0.006$), suggesting that while the difference in predicted depressive symptoms scores between HA users and non-users was 0.14 factor scores for good hearers, it approximated zero (-0.01 factor scores) for those with poor hearing. Functional hearing remained a significant predictor of depression ($p < 0.001$) in all cases. Generally, HA usage had no impact on depression among those with poor functional hearing.

Contribution of other physical health problems and social engagement to the depression factors

Because functional hearing interacted significantly with age, and in some cases with gender, regression analyses were performed separately for females and males below 50 years of age, and for females and males above 60 years of age. Table IV shows the distribution of replies across response categories for the potential confounding measures when stratified by age and gender. According to a Chi-square test the younger participants reported a significantly lower number of serious medical problems and vascular problems than the older participants ($p = 0.005$ and $p < 0.001$, respectively). Further, the younger male participants reported a significantly lower frequency of visits from family and friends than the older female participants ($p < 0.001$). As FH Noise was the hearing measure which showed the strongest association with both depression factors, only data for this hearing measure is presented in

details. With a few exceptions (vascular problems and frequency of visits vs depressive episodes), the additional independent variables contributed significantly to both depression factors for at least some of the participant groups. The effect of FH Noise remained significant in all cases, but with a reduced effect size; 17% to 26% for both depression factors. The least reduced effect size was observed for the older female participants. Table V shows the contribution of each measure to depressive episodes and symptoms for each of the four participant groups. For all four groups, the measures that best predicted depressive symptoms were overall health rating followed by FH Noise. Together with other serious medical conditions, these two measures also best predicted depressive episodes among the younger participants. Among the older participants the same measures together with respiratory problems were relatively stronger predictors of depressive episodes, although the predictions were not nearly as strong as for the younger participants. With respect to depressive symptoms, similar findings were obtained for BESRTn. However, BESRTn was not a significant predictor of depressive episodes when controlling for other physical health problems and social engagement. Overall, both other physical health problems and social engagement showed partial confounding effects, with some of the physical health measures being a stronger predictor of the depressive factors than functional hearing.

Discussion

Based on observations from over 100,000 community-dwelling individuals aged between 39 and 70 years, this study found a significant independent association between poorer functional hearing, whether reported or measured behaviourally, and higher levels of two multifactorial measures of depression when controlling for age and gender. The mechanistic pathway for the associations is expected to be via the detrimental effect hearing problems have on the ability to communicate effectively. Communication is one of the most important

aspects of everyday life, and failure to engage socially can lead to a perceived reduction in quality of life and hence to poorer mental well-being (Dawes et al., 2015, Strawbridge et al., 2000, Weinstein and Ventry, 1982).

Previous studies (Dalton et al., 2003, Saito et al., 2010, Tambs, 2004) have shown that self-reported functional hearing has a stronger association than hearing loss measured by pure tone audiometry with mental health. This study extends these reports to show that self-reported relative to measured functional hearing (when the focus is on hearing ability in noise), remained a stronger predictor of both depression factors; with the difference in measurement method having a stronger effect on the factor representing a more debilitating form of depression (depressive episodes). In fact, the smallest effect size of hearing, which was reduced to almost zero for the participants in their 60s, was seen for the association between the behavioural measure of functional hearing and depressive episodes. This association was further the only one that was fully confounded by measures of other physical health problems. Although the different measures of functional hearing correlated significantly with each other, they were not entirely consistent (cf. Figure 1), which is in agreement with previous reports (Kamil et al., 2015, Lutman et al., 1987, Pichora-Fuller, 1998). Imperfect reliability of self-reports has previously been blamed for the discrepancy in behavioural and subjective data (Tambs, 2004); however, it is likely that participants answered the questions according to their beliefs, coloured by personality traits and mental state, but also shaped by their own specific experience of real-life communication situations. For example, a pessimistic outlook, an adverse reaction to noise, or a depressive disorder may bias a negative self-report on functional hearing. Specifically, Erdman and Demorest (1998) have shown that adjustment to hearing impairment is influenced by such factors as the individual's psychosocial make-up, environment, and behaviour patterns. As data analysed in

this study was cross-sectional, no firm conclusions can be made with respect to the temporal order of reported functional hearing and the depression factors. We speculate that in this sample, there were cases of both orders; i.e. for some people a perceived hearing problem was the primary factor causing depression and for others depression was primarily caused by other factors and affected their perception of how well they hear. From this perspective, it would seem desirable to base future studies on hearing and depression on behavioural, or objective, measures of hearing. Using a factor analytic method, various measures associated with the auditory profile, such as sensitivity, psychoacoustic ability, and speech perception in noise could be considered to form a consolidated robust measure of functional hearing. Alternatively, if using self-reports, analyses should aim to control for aetiological factors. Further, in agreement with Lupsakko et al. (2002), this study found that the effect of hearing was generally greater on a less debilitating form of depression, covering a mixture of depressed mood associated with neuroticism and life satisfaction, than reported depressive episodes. These findings suggest that future studies should clearly consider the type or severity of depression they wish to target.

There was no evidence that HA usage would mitigate depression, especially not among those with poor functional hearing. As the number of hearing aid users was low (a total of 2,702 with only 41 and 126 in the categories of good FH General and good FH Noise, respectively), this finding should be interpreted with some caution. The suggestion is, however, in agreement with one recent cross-sectional study that also focused on a population less than 70 years of age and used data on functional hearing in noise (Nachtegaal et al., 2009). Perhaps, in the age bracket 40-70 years the negative effects of having to wear a HA may balance out the positive effects the device has on improving communication abilities. The above suggestions contradict other reports (Acar et al., 2011, Boi et al., 2012, Gopinath et al., 2009,

Lee et al., 2010, Mener et al., 2013, Mulrow et al., 1992) that focused on either a small number of volunteers in a clinical or primary care setting from the time of fitting with hearing aids and up to 3-12 months post-fitting, or community-dwelling older adults. Both populations would most likely be more accepting of their hearing loss given that they had decided to do something about it or belonged to the older cohort, and acceptance of hearing disability has been found to reduce symptoms of depression (Manchaiah and Andersson, 2014). Overall, the effect of HA usage remains unclear and, as previously pointed out, the causation of an association is not well understood (Horowitz, 2003).

We note that the main findings of a significant association between functional hearing and depression, and a non-significant effect of hearing aid usage on the association, parallel recent results based on the UK Biobank resource presented by Dawes et al. (2015). In that study, the relationship between the behaviourally measured functional hearing variable and cognition was examined in a statistical model, with hearing aid usage, social isolation and a single-item self-reported measure of depression as potential confounders.

Results from this study further confirm recent reports of stronger associations between poor hearing and depression among people in their 40s compared to people 60 years of age and older (Nachtegaal et al., 2009, Tambs, 2004). As speculated in the earlier reports, this finding could be because the middle-aged population is less accepting of a declining hearing ability than older people, who can associate their hearing handicap with a natural ageing process. Middle-aged people are also at more critical stages of their career and it has been found that deaf people have more difficulty finding work (Rydberg et al., 2010), and that hearing-impaired people in comparison to their normal-hearing peers in similar jobs report poorer physical health status and psychological well-being (Danermark and Gellerstedt, 2004). It has

also been suggested that younger generations may experience a higher burden of depression during their lifetime than previous generations (Blazer et al., 1994), which could explain why even among those with good hearing, higher levels of depression were reported by the younger than older participants (cf. Figure 3). With respect to the subjective measures of functional hearing, the recent findings by Kamil et al (2015), that middle-aged people tend to overestimate and older people underestimate their hearing ability, make the stronger effects of hearing on the depression factors observed for the younger participants appear more remarkable. The consistent findings in recent studies that hearing has a greater effect on depression among middle-aged than older people, warrant a more systematic investigation into the pathways between hearing and depression for this population, and on ways for society to better support middle-aged hearing-impaired people.

For both the younger and older participants in this study sample, the association between functional hearing and the depression factors remained significant when further controlling for measures of other physical health problems and social engagement. Including such measures in the regression analyses, however, did reduce the associations, suggesting partially confounding effects from other physical health problems and social engagement. Particularly, overall health ratings showed significant and stronger associations with depressive symptoms than functional hearing, while serious medical problems showed slightly stronger associations with depressive episodes than functional hearing; especially for the younger participants. Strong associations have previously been reported between depression and physical health (Beekman et al., 1997, Kroenke et al., 1994, Mulsant et al., 1997). The weaker association between other physical health measures and depressive episodes (the more debilitating depression factor), seen in this study may be because participants with severe medical problems and depression, especially among the older cohort,

declined participation. Still, as mentioned earlier, other physical health problems did fully confound the association between the behavioural measure of functional hearing and depressive episodes. Interestingly, relative to chronic physical diseases and functional hearing, the social engagement measures contributed less, if at all, to the prediction of the depression factors in this sample.

This study found a strong gender effect, with women generally reporting higher levels of both depressive episodes and symptoms. Female gender has been identified in a meta-analysis to be a risk factor for depression among community-dwelling residents 50 years and older (Cole and Dendukuri, 2003). There have previously been contradicting reports to suggest that the association between hearing and symptoms of depression was stronger among females (Ives et al., 1995), or males (Tambs, 2004). In this study, the significant interaction effects between hearing and gender observed for depressive episodes support the former study.

The main strengths of this particular study are the number of observations from a community-dwelling population, and the derivation of the two depression factors from a wide range of self-reports, consolidated to provide a sophisticated continuous variable and a more reliable picture of each participant's state across a more (depressive episodes) and less (depressive symptoms) debilitating form of depression. The study also had the following limitations that may influence findings: 1) A low response rate: only 5.4% of candidates invited to participate in the data collection for the UK Biobank resource accepted, and less than a third of this population provided responses to all measures of interest in this study, which means that the study sample cannot be deemed totally random. 2) The use of non-standardised tests: because the UK Biobank resource aimed to collect a wide range of health and lifestyle related measures, comprehensive and standardised measures and questionnaires on, for example,

hearing loss, hearing handicap, and depression that take more time and resources to administer were not included, making it difficult to quantitatively compare the findings of this study with other results. Specifically, the subjective hearing difficulty parameters were based on a single direct question, which makes the measures prone to reliability issues. 3) Choice of controlled parameters: this study controlled for age and gender, and considered other physical health problems and social engagement as potential confounders, but other aetiological data that may have a strong association with different forms of depression were not included.

Conclusion

Irrespective of measurement method, functional hearing was independently associated with multifactorial measures of depression when controlling for age and gender. The association was generally stronger in the younger participants (in their 40s). As this population is expected to be independent and well integrated in the work force and society, it would be of interest to further explore the mechanistic pathways between hearing and depression for this age group with a view to be able to provide better rehabilitation options. Further, the associations were stronger when considering self-reports of functional hearing, especially in the prediction of the more debilitating depressive episodes factor. Assuming that self-reports can be biased by factors associated with depression, it is recommended to base future studies on behavioural measures of functional hearing. Hearing aid usage did not mitigate the effect of functional hearing on the depression factors, but the effects of functional hearing were reduced when controlling for measures of other physical diseases in particular.

Acknowledgements and Declaration of Interest

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Table I: The loadings of four constructs and five transformed measures (see text for details) associated with depression on two factors referred to as ‘depressive episodes’ and ‘depressive symptoms’.

Variable	Depressive episodes	Depressive symptoms
Neuroticism depression	0.18	0.78
Neuroticism anxiety	0.11	0.63
Satisfaction with life	0.14	0.56
Feeling down	0.20	0.69
Duration of depression	0.84	0.18
Frequency of depression	0.81	0.24
Duration of unenthusiasm	0.86	0.17
Frequency of unenthusiasm	0.84	0.24
Duration of mania	0.27	0.32

Table II: The significance levels for functional hearing and its interactions with gender and age when associated with depressive episodes and symptoms. The denominator df was 101,099. The estimated effect sizes in factor scores (factor scores per 10 dB SNR for BESRTn) are also shown for the different hearing measures.

Effect	Depressive episodes					Depressive symptoms				
	F-value	df	p-level	E	Std Err of E	F-value	df	p-level	E	Std Err of E
FH General	118.5	3	< 0.001	0.14	0.007	421.9	3	< 0.001	0.22	0.006
FH General * Gender	16.6	1	< 0.001			9.1	1	0.003		
FH General * Age	34.7	1	< 0.001			52.5	1	< 0.001		
FH Noise	198.8	3	< 0.001	0.16	0.006	995.8	3	< 0.001	0.30	0.005
FH Noise * Gender	14.6	1	< 0.001			0.8	1	0.38		
FH Noise * Age	59.2	1	< 0.001			128.2	1	< 0.001		
BESRTn	7.3	3	< 0.001	0.08	0.020	80.9	3	< 0.001	0.27	0.017
BESRTn * Gender	0.6	1	0.44			0.2	1	0.65		
BESRTn * Age	15.6	1	< 0.001			12.0	1	< 0.001		

FH General = reported functional hearing in general; FH Noise = reported functional hearing in noise; BESRTn = better ear speech reception threshold in noise; E = effect size; Std Err = Standard Error.

Table III: The significance levels for hearing aid usage and its interactions with functional hearing when associated with depressive episodes and symptoms. The denominator df was 101,080. The estimated effect sizes in factor scores (calculated for the average SNR for BESRTn) are also shown for hearing aid usage.

Effect	Depressive episodes					Depressive symptoms				
	F-value	df	p-level	E	Std Err of E	F-value	df	p-level	E	Std Err of E
HA usage	1.19	2	0.30	-0.11	0.105	1.24	2	0.29	0.10	0.089
HA usage * FH General	1.86	1	0.17			2.23	1	0.14		
HA usage	0.28	2	0.76	-0.12	0.055	2.34	2	0.10	0.05	0.046
HA usage * FH Noise	0.04	1	0.84			3.68	1	0.06		
HA usage	4.29	2	0.02	0.06	0.044	21.7	2	<0.001	0.12	0.037
HA usage * BESRTn	0.31	1	0.58			7.45	1	0.006		

HA = hearing aid; FH General = reported functional hearing generally, FH Noise = reported functional hearing in noise; BESRTn = better ear speech reception threshold in noise; E = effect size; Std Err = Standard

Error.

Table IV: The percentage distributions across response categories obtained for a variety of physical health problems and social engagement measures for females and males less than 50 years of age, and over 60 years of age.

Variable (response categories)	F < 50 years N = 12,048	M < 50 years N = 10,320	F > 60 years N = 18,983	M > 60 years N = 20,859
FH Noise (No/Yes)	(79,21)	(73,27)	(68,32)	(52,48)
Overall health (Excellent/Good/Fair/Poor)	(20,60,17,3)	(16,57,22,4)	(16,64,18,2)	(15,59,22,4)
Serious medical problems (None/One/Two or more)	(76,21,3)	(74,23,3)	(59,31,10)	(61,31,8)
Vascular problems (None/One/Two or more)	(89,11,0)	(85,14,1)	(66,31,3)	(55,37,8)
Respiratory problems (None/One/Two or more)	(63,29,8)	(66,27,7)	(70,24,6)	(73,22,5)
Frequency of visits (Never/Every few months/ Once a month/Once a week/2-4 times weekly/daily)	(1,6,14,38,30,11)	(1,9,18,43,23,6)	(1,4,9,30,39,18)	(2,6,13,35,33,11)
Social activities (None/One/Two/Three or more)	(33,43,20,4)	(30,45,22,3)	(26,41,25,8)	(28,46,21,5)

FH Noise = reported functional hearing in noise; F = females; M = males.

Table V: The non-standardised regression coefficient, significance level, and partial correlation coefficient for potential confounding measures on the association between reported functional hearing in noise and depressive episodes and symptoms shown for females and males less than 50 years of age, and over 60 years of age.

Parameters	F < 50 years			M < 50 years			F > 60 years			M > 60 years		
	b	p-level	PC	b	p-level	PC	b	p-level	PC	b	p-level	PC
<i>Depressive episodes:</i>												
FH Noise	0.17	<0.001	0.07	0.14	<0.001	0.07	0.10	<0.001	0.05	0.06	<0.001	0.04
Age	0.00	0.63	0.00	-0.00	0.89	-0.00	-0.02	<0.001	-0.06	-0.02	<0.001	-0.05
Overall health	0.18	<0.001	0.12	0.11	<0.001	0.08	0.06	<0.001	0.04	0.05	<0.001	0.04
Serious medical	0.19	<0.001	0.10	0.19	<0.001	0.11	0.10	<0.001	0.07	0.07	<0.001	0.05
Vascular problems	0.00	0.92	0.00	0.06	0.01	0.02	-0.02	0.23	-0.01	0.00	0.79	0.00
Respiratory problems	0.08	<0.001	0.05	0.07	<0.001	0.05	0.08	<0.001	0.05	0.09	<0.001	0.06
Friend/family visits	-0.01	0.15	-0.01	0.00	0.71	0.00	-0.00	0.80	-0.00	-0.00	0.51	-0.00
Social activities	0.03	0.003	0.03	0.01	0.42	0.01	0.05	<0.001	0.05	0.03	<0.001	0.03

<i>Depressive symptoms:</i>												
HD Noise	0.27	<0.001	0.14	0.27	<0.001	0.15	0.19	<0.001	0.13	0.18	<0.001	0.14
Age	-0.01	<0.001	-0.03	-0.01	<0.001	-0.04	-0.01	<0.001	-0.03	-0.02	<0.001	-0.06
Overall health	0.43	<0.001	0.35	0.40	<0.001	0.33	0.35	<0.001	0.30	0.30	<0.001	0.28
Serious medical	0.01	0.64	0.00	0.06	<0.001	0.04	-0.03	<0.001	-0.03	0.02	0.04	0.01
Vascular problems	0.07	0.002	0.03	0.09	<0.001	0.04	0.01	0.21	0.01	0.03	<0.001	0.02
Respiratory problems	0.01	0.39	0.01	0.05	<0.001	0.03	0.03	0.001	0.03	0.05	<0.001	0.04
Friend/family visits	-0.04	<0.001	-0.05	-0.04	<0.001	-0.06	-0.05	<0.001	-0.07	-0.05	<0.001	-0.08
Social activities	-0.05	<0.001	-0.05	-0.02	0.01	-0.03	-0.05	<0.001	-0.06	-0.02	<0.001	-0.03

FH Noise = reported functional hearing in noise; F = females; M = males; b = non-standardised regression coefficient; PC = partial correlation coefficient.

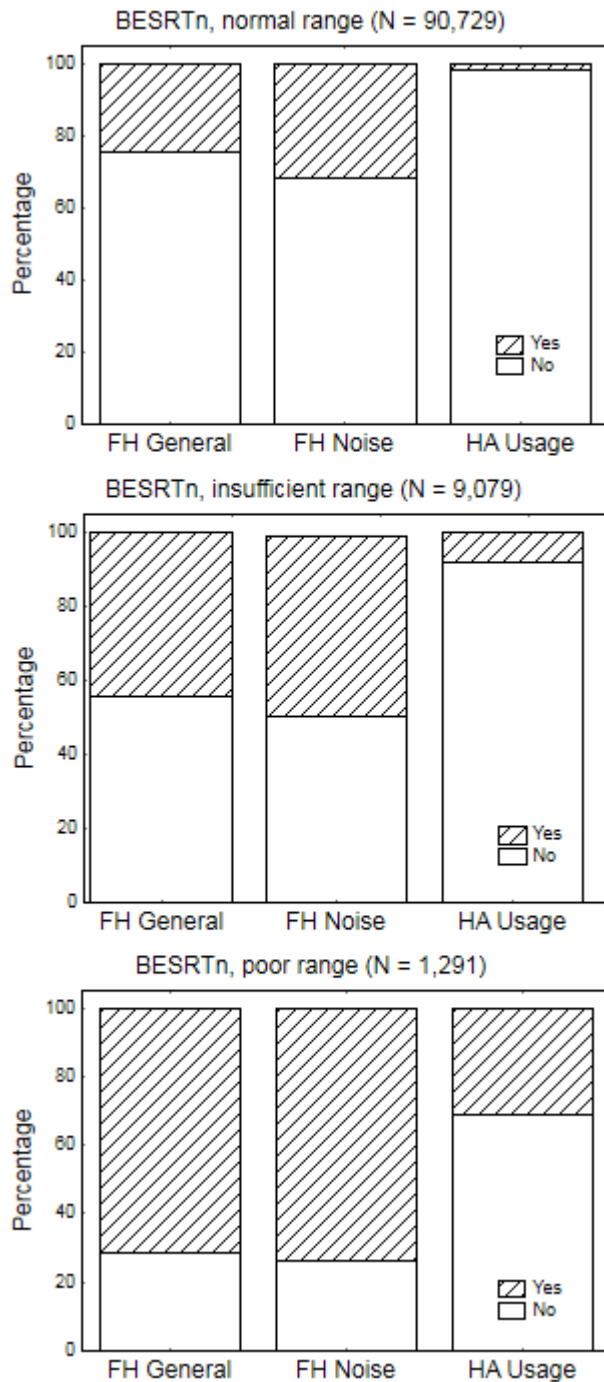


Figure 1: The proportion of participants reporting positively or negatively to questions about having poor functional hearing in general (FH General) or in noise (FH Noise), or using hearing aid/s (HA Usage) among those behaviourally showing normal (top), insufficient (middle), and poor (bottom) ability to understand speech in noise.

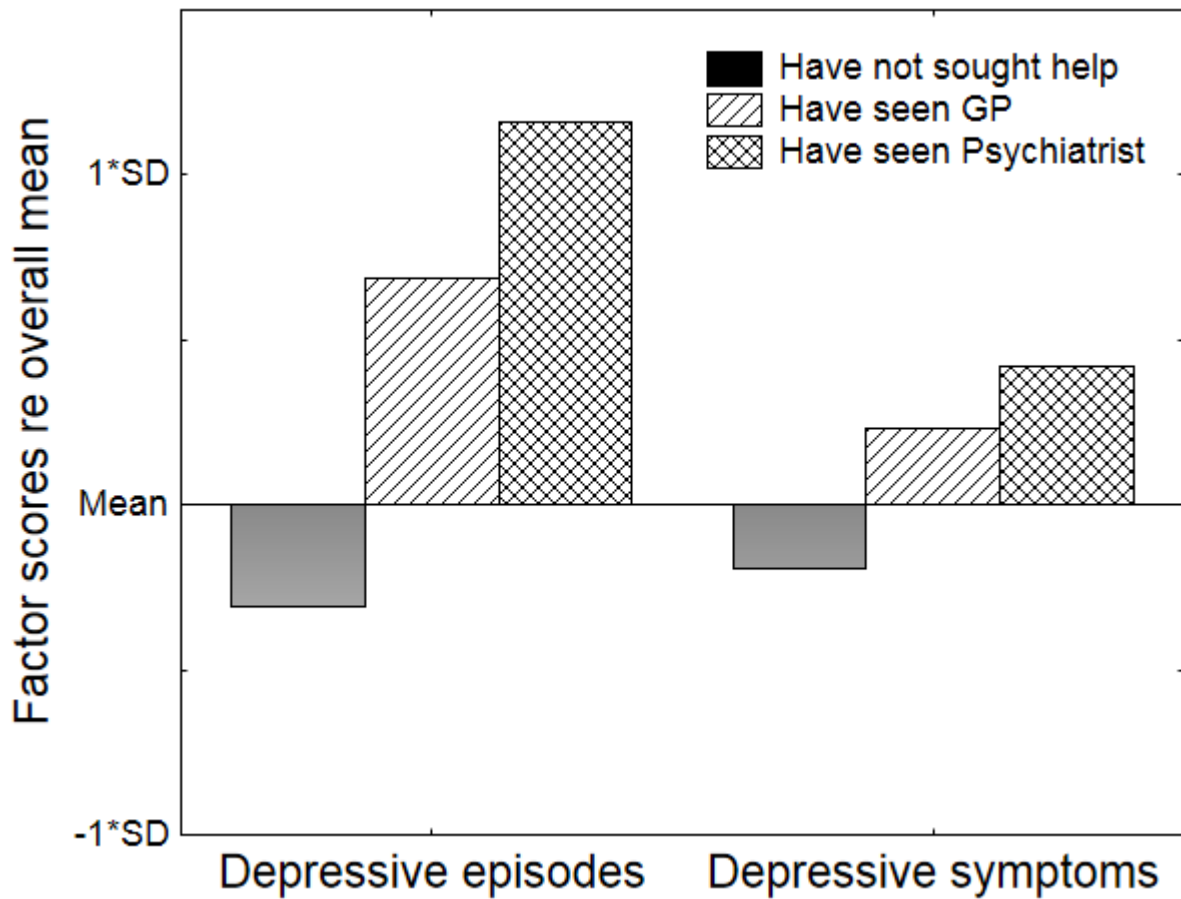


Figure 2: The average factor scores obtained for depressive episodes and symptoms, relative to the overall mean, by participants who reportedly had not sought help (full bars), had seen a General Practitioner (GP) (hatched bars), or had seen a Psychiatrist (crossed bars) for mental health problems.

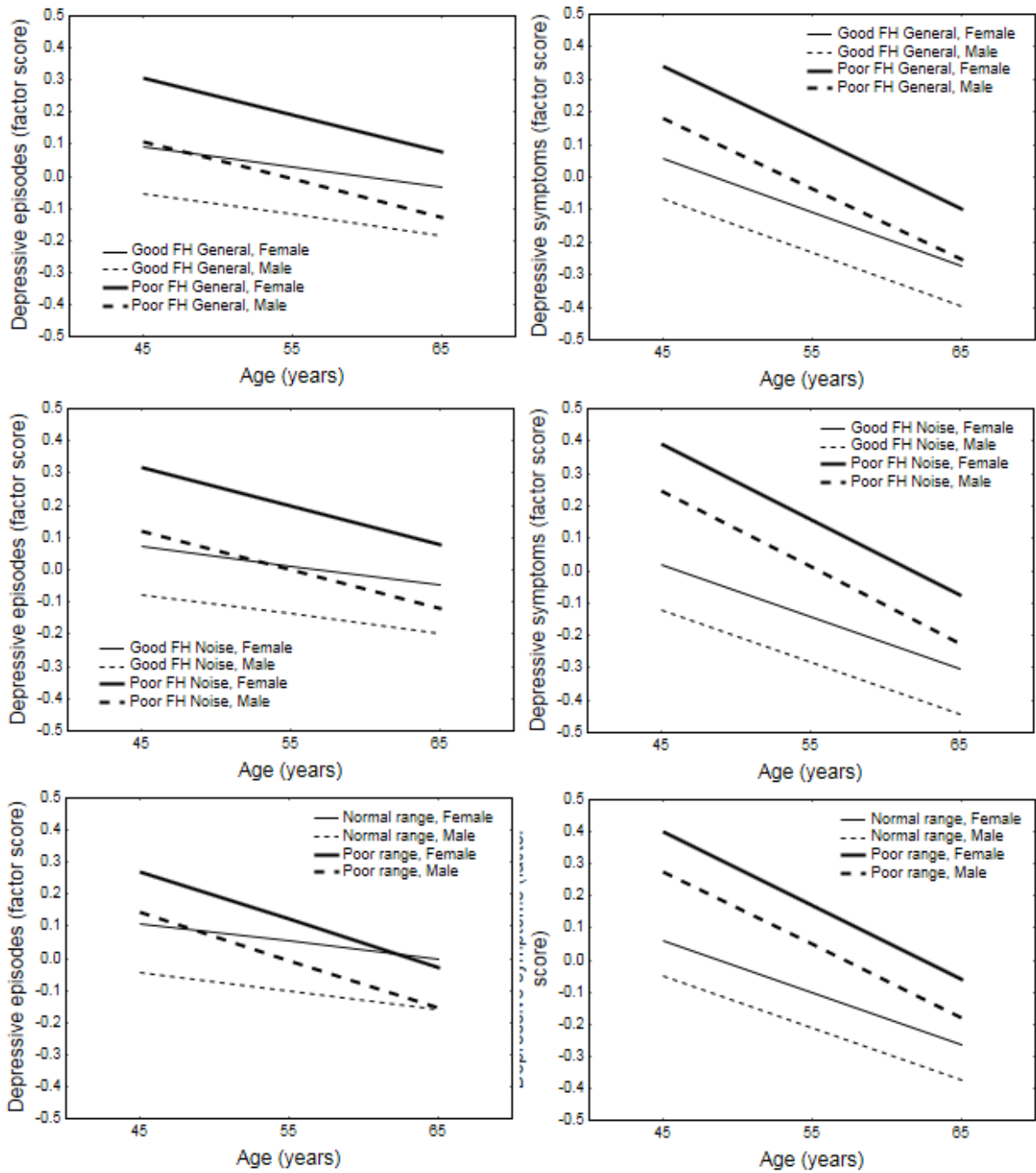


Figure 3: Predicted interactions of age, gender, and hearing difficulty for reported functional hearing in general (top), reported functional hearing in noise (middle), and measured functional hearing in noise (bottom) for depressive episodes (left-hand column) and depressive symptoms (right-hand column).

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