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Hearing Difficulties and Tinnitus in Construction, Agricultural, Music, and Finance Industries: Contributions of Demographic, Health, and Lifestyle Factors

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Abstract

High levels of occupational noise exposure increase the risk of hearing difficulties and tinnitus. However, differences in demographic, health, and lifestyle factors could also contribute to high levels of hearing difficulties and tinnitus in some industries. Data from a subsample ($n = 22,936$) of the U.K. Biobank were analyzed to determine to what extent differences in levels of hearing difficulties and tinnitus in *high-risk* industries (construction, agricultural, and music) compared with *low-risk* industries (finance) could be attributable to demographic, health, and lifestyle factors, rather than occupational noise exposure. Hearing difficulties were identified using a digits-in-noise speech recognition test. Tinnitus was identified based on self-report. Logistic regression analyses showed that occupational noise exposure partially accounted for higher levels of hearing difficulties in the agricultural industry compared with finance, and occupational noise exposure, older age, low socioeconomic status, and non-White ethnic background partially accounted for higher levels of hearing difficulties in the construction industry. However, the factors assessed in the model did not fully account for the increased likelihood of hearing difficulties in high-risk industries, suggesting that there are additional unknown factors which impact on hearing or that there was insufficient measurement of factors included in the model. The levels of tinnitus were greatest for music and construction industries compared with finance, and these differences were accounted for by occupational and music noise exposure, as well as older age. These findings emphasize the need to promote hearing conservation in occupational and music settings, with a particular focus on high-risk demographic subgroups.

Keywords

hearing difficulties, tinnitus, occupation, noise exposure, epidemiology

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Introduction

Hearing difficulties and tinnitus are common risks associated with professions where there are high levels and long durations of noise exposure such as in construction, agricultural, and music industries (Nelson, Nelson, Concha-Barrientos, & Fingerhut, 2005; Sliwinska-Kowalska & Davis, 2012; Stucken & Hong, 2014; Tak, Davis, & Calvert, 2009). Between 7% and 21% of hearing loss in adults is attributable to occupational noise (Dobie, 2008; Lie et al., 2016; Nelson et al., 2005), with noise-induced hearing loss (NIHL) being one of the most common occupational diseases (Fausti, Wilmington, Helt, Helt, & Konrad-Martin, 2005; Le, Straatman,

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Lea, & Westerberg, 2017; Themann, Suter, & Stephenson, 2013). Compared with 7% of nonnoise exposed workers, 23% of U.S. workers exposed to occupational noise reported having a hearing impairment, while 15% of noise exposed workers reported tinnitus compared with 5% of nonexposed workers (Masterson, Themann, Luckhaupt, Li, & Calvert, 2016). With respect to specific industries, 25% of noise exposed U.S. construction workers (Masterson, Deddens, Themann, Bertke, & Calvert, 2015), 65% to 67% of farmers (Kerr, McCullagh, Savik, & Dvorak, 2003; Marvel, Pratt, Marvel, Regan, & May, 1991), and 37% to 58% of classical musicians (for a review, see Zhao, Manchaiah, French, & Price, 2010) were found to have hearing impairments based on audiometric data. Jansen, Helleman, Dreschler, and de Laat (2009) showed that approximately half of the musicians in their study complained of tinnitus, and Hong (2005) demonstrated that 38% of construction workers reported experiencing tinnitus.

The current permissible noise limit in the United Kingdom is 85 dBA for 8-hr duration, which is reduced by half for each 3 dBA increase in noise intensity (Control of Noise at Work Regulations, 2005; for similar regulations, also see National Institute of Occupational Safety and Health [NIOSH], 1998). Typical average noise equivalent exposures (based on an 8-hr time-weighted average) for construction workers are 72 to 112 dBA (Fernández, Quintana, Chavarría, & Ballesteros, 2009; Neitzel, Seixas, Camp, & Yost, 1999; Neitzel, Stover, & Seixas, 2011; Seixas et al., 2012), 75 to 98 dBA for classical musicians (McBride et al., 1992; Pawlaczyk-Łuszczyńska, Dudarewicz, Zamojska, & Śliwinska-Kowalska, 2011; Royster, Royster, & Killion, 1991; Schmidt et al., 2011), and 62.6 to 92.1 dBA for agricultural workers (McBride, Firth, & Herbison, 2003; Milz, Wilkins, Ames, & Witherspoon, 2008; Williams et al., 2015). However, while exposure to high levels of noise may be the primary cause of hearing difficulties and tinnitus, demographic, health, and lifestyle factors may also be a contributing factor (Agrawal, Platz, & Niparko, 2008; Cruickshanks et al., 2003; Cruickshanks, Klein, et al., 1998; Cruickshanks, Wiley, et al., 1998; Ferrite & Santana, 2005; Heller, 2003). For example, ageing is a well-documented risk factor for hearing difficulties (Cruickshanks, Wiley, et al., 1998; Davis et al., 2016; Dubno, Dirks, & Morgan, 1984; Lin et al., 2013; Patterson, Nimmo-Smith, Weber, & Milroy, 1982) and tinnitus (Negrila-Mezei, Enache, & Sarafoleanu, 2011; Rosenhall, 2003; Sanchez, 2004). Other demographic risk factors include socioeconomic status (SES), ethnicity, education level, cognition, genetics, and gender, while modifiable health and lifestyle risk factors include smoking, lack of exercise, poor diet, diabetes, and cardiovascular disease, for both hearing difficulties (e.g., Agrawal et al., 2008; Daniel, 2007; Dawes, Cruickshanks, et al., 2014; Moore et al., 2014) and tinnitus (e.g., Heller, 2003; Hoffman & Reed, 2004; Sanchez, 2004). Noise exposure may also interact with demographic, health, and lifestyle factors (Ferrite & Santana, 2005; Mizoue, Miyamoto, & Shimizu, 2003). For example, Ferrite and Santana (2005) estimated that the combined effects of age, smoking, and noise exposure on hearing loss were greater than the sum of effects from each factor.

Determining the impact of noise exposure in relation to hearing difficulties and tinnitus among high-risk industries is problematic because demographic, health, and lifestyle factors that impact on hearing may also vary between industries. For instance, one might predict a higher proportion of males and higher levels of physical activity in agricultural and construction industries compared with finance. Furthermore, it is unknown whether music noise exposure also contributes to hearing difficulties and tinnitus in high-risk industries, and whether certain industries are also more exposed to music noise than others. For example, Tufts and Skoe (2018) showed that musicians had higher levels of both occupational and recreational music noise exposure than nonmusicians, and that recreational music noise exposure contributed more to some musicians' total noise exposure than occupational musical activities. Therefore, it is important to consider music noise exposure as well as other high-risk demographic, health, and lifestyle factors when assessing hearing function in high-risk groups. Understanding the contributions of occupational noise, recreational (i.e., music) noise, demographic, health, and lifestyle factors to hearing health could have important implications for developing interventions to promote healthy hearing. For example, hearing conservation program for both occupational (see Verbeek, Kateman, Morata, Dreschler, & Mischke, 2014) and recreational (see Zhao, French, Manchaiah, Liang, & Price, 2012) settings could be combined with interventions that target modifiable health and lifestyle risk factors for hearing health, which may be particularly relevant for certain industries or demographic subgroups.

In this study, we aimed to evaluate whether demographic, health, and lifestyle factors including music noise exposure could account for the excess risk of hearing difficulties and tinnitus in industries at high risk of hearing problems due to occupational noise exposure (construction, agricultural, and music industries) compared with an industry with low levels of occupational noise exposure (finance).

Method

Participants

In this retrospective cross-sectional study, the participant sample was drawn from the U.K. Biobank resource for epidemiology, which contains data for more than 500,000 persons aged 40 to 69 years across England, Scotland, and Wales (Collins, 2012). All data were collected between 2006 and 2010. Individuals registered with the National Health Service and living within a 25-mile radius of one of 22 U.K. Biobank assessment centers were invited to participate (Allen et al., 2012). Participation involved completion of touch-screen questionnaires and nurse-led interviews to collect epidemiological data on demographic, health, environmental, and lifestyle factors. Measures of hearing function and tinnitus questions (described later) were added part way through data collection, and so hearing function and tinnitus data are available for a subset of the U.K. Biobank sample (see Table 1). If participants reported that they were currently employed or self-employed, the interviewer was prompted to ask the participant to describe their current occupation. The occupation title was coded according to the U.K. Standard Occupational Classification (Office for National Statistics, 2000; see Supplementary Materials). Industries of interest were construction (classified as machinery, construction plant, or building work; $n = 9{,}249$), agricultural (classified as farming or agriculture; $n = 2{,}081$), music (classified as a performing musician or director or conductor; $n = 395$), and finance (classified as banking or finance; $n = 11{,}211$; total: $n = 22{,}936$; see Table 1). Note that previous employment history was not captured by the U.K. Biobank questionnaires, and inclusion was based on current employment status; unemployed and retired individuals were not included in the analysis.

U.K. Biobank procedures were approved by the North West Multi-centre Research Ethics Committee, and all participants provided written informed consent.

Procedures

Hearing function. Participants completed a shortened version of the digits-in-noise (DIN) test; a test of speech recognition in background noise, which correlates strongly with pure-tone audiometric thresholds (Smits, Kapteyn, & Houtgast, 2004). For the U.K. Biobank version of the DIN test, 15 sets of English monosyllabic digits were presented. Each ear was tested separately, with the order of testing randomized between participants. Stimuli were presented via circumaural

Table 1. Hearing Difficulties, Tinnitus, Demographic, Health, and Lifestyle Factors for the Overall Subsample, and Split by Agricultural, Construction, Music, and Finance Industries.

Factors	*N* participants	Overall (*N* = 22,936)	Agricultural (*N* = 2,081)	Construction (*N* = 9,249)	Music (*N* = 395)	Finance (*N* = 11,211)	*p*
Hearing difficulties[a]	9,035	10.70%	14.36%	13.40%	4.88%	8.26%	<.001
Tinnitus, yes[a]	9,312	17.29%	18.59%	20.60%	23.95%	14.26%	<.001
Age[b]	22,936	53.94 (7.87)	55.10 (7.98)	54.47 (7.95)	54.88 (7.89)	53.25 (7.71)	<.001
Gender, male[a]	22,936	72.29%	72.47%	97.09%	59.24%	52.26%	<.001
Ethnicity, White[a]	22,832	95.34%	98.60%	96.12%	97.96%	93.99%	<.001
Townsend quartile[a]	22,909						<.001
Most affluent		31.98%	28.01%	29.06%	22.03%	35.48%	
Second quartile		26.61%	30.13%	26.25%	18.23%	26.55%	
Third quartile		22.27%	22.52%	22.86%	28.35%	21.52%	
Most deprived		19.14%	19.35%	21.83%	31.39%	16.45%	
Work noise exposure, high[a]	9,390	27.53%	36.29%	50.12%	4.96%	8.10%	<.001
Music noise exposure, high[a]	9,384	14.79%	15.03%	18.64%	46.75%	10.61%	<.001
Smoking status[a]	22,843						<.001
Current smoker		11.84%	12.31%	14.87%	12.47%	9.24%	
Ex-smoker		33.32%	32.38%	36.43%	32.06%	30.97%	
Nonsmoker		54.84%	55.31%	48.70%	55.47%	59.79%	
Alcohol consumption, yes[a]	22,895	95.12%	93.50%	95.57%	93.15%	95.12%	<.001
Ototoxic medication, yes[a]	22,936	36.75%	36.47%	37.03%	30.13%	36.79%	.05
Physical activity, inactive[a]	10,113	28.23%	14.60%	26.96%	25.11%	30.83%	<.001
Body mass index[b]	22,618	27.54 (4.36)	26.81 (4.24)	28.07 (4.09)	25.94 (4.40)	27.29 (4.54)	<.001
Diabetes, yes[a]	22,936	4.11%	3.27%	4.52%	3.04%	3.97%	.02
Cardiovascular disease, yes[a]	22,936	7.39%	8.31%	8.58%	4.81%	6.32%	<.001
Hypertension, yes[a]	22,936	54.36%	53.87%	60.64%	43.04%	49.67%	<.001
High cholesterol, yes[a]	22,936	15.21%	13.41%	17.19%	9.37%	14.12%	<.001

Note. Comparisons between job categories were conducted. Pearson's χ^2 tests for categorical variables and one-way analysis of variance for continuous variables ($\alpha = .001$). *SD* = standard deviation.

[a]Descriptive statistics for all categorical (%) variables.

[b]Descriptive statistics for all continuous (mean ± *SD*) variables.

headphones (Sennheiser HD-25) at a comfortable level set by participants. Digit triplets (e.g., 2–5–3) were presented against a background of speech-shaped noise matched to the complete set of the nine monosyllabic digits (0–9, "0" was/oh/, and 7 was excluded). Participants were required to identify and key in the three digits via a touch-screen interface. The sound level of the background noise varied adaptively after each presentation depending on whether all three digits were correctly identified. The speech reception threshold was estimated based on the average signal-to-noise ratio (SNR) from the last eight triplets. The SNR varied between −12 and +8 dB, with more positive scores indicating poorer speech hearing ability. Hearing difficulties were identified based on the performance of the better ear relative to a reference group of normal hearing participants aged 18 to 29 years (Dawes, Fortnum, et al., 2014), such that participants were classified as having *normal hearing* for SNR values below −5.5 dB or having *hearing difficulties* for SNR values above −5.5 dB. Difficulty hearing in background noise is the most common hearing complaint (Pienkowski, 2017); therefore, the assessment of hearing function using a test of number recognition in background noise represents an ecologically valid and objective index of hearing.

Tinnitus. Participants were asked "Do you get or have you had noises (such as ringing or buzzing) in your head or in one or both ears that lasts more than 5 minutes at a time?" with a choice of responses: (a) Yes, now most or all of the time; (b) Yes, now a lot of the time; (c) Yes, now some of the time; (d) Yes, but not now, but have in the past; (e) No, never; (f) Do not know; or (g) Prefer not to answer. The presence of tinnitus was characterized by participants currently having symptoms at least "now some of the time."

Demographic factors. Demographic factors included age, sex, SES, and ethnicity. Ethnicity was coded according to *White* or *non-White* ethnic groups based on U.K. 2001 census categories (see U.K. Biobank protocol; http://www.ukbiobank.ac.uk/). The Townsend index was used as a proxy measure of SES; a composite measure of unemployment, non car ownership, non home ownership, and household overcrowding based on the area of residence (Townsend, Phillimore, & Beattie, 1988). The Townsend index is expressed in terms of a *z*-score. These scores were categorized into quartiles, with the lowest scores or quartile representing more affluent status.

Health and lifestyle factors.

Body mass index and physical activity. Body mass index (BMI) was calculated as weight (kg) divided by height (m^2). Physical activity was measured using the question "Yesterday, about how long did you spend doing activities that needed moderate effort, making you somewhat out of breath? For example, walking upstairs, going to the gym, jogging, energetic dancing, aerobics, most sports, using heavy power tools, and other physically demanding DIY and gardening." Participants were classified as *inactive* if they reported doing less than 10 minutes moderate activity, and *active* for any other lengths of moderate activity over 10 minutes.

Smoking and alcohol consumption. Smoking status was based on the responses to two questions "Do you smoke tobacco now?" and "In the past, how often have you smoked tobacco?," with participants classified as *current smoker* (currently smoking occasionally or on most or all days), *ex-smoker* (previously smoking occasionally or on most or all days), or *nonsmoker* (never smoked or reported just having tried smoking once or twice). Alcohol consumption was classified on the basis of participants responses to the question "About how often do you drink alcohol?," with *nondrinkers* identified as having "never" drank alcohol, and *drinkers* identified on the basis of the remaining options ("special occasions only," "one to three times a month," "once or twice a week," "three or four times a week," "daily or almost daily").

Diabetes, cardiovascular disease, high cholesterol, hypertension, and ototoxic medication. Diabetes was identified if the participant reporting having either Type 1 or Type 2 diabetes or reported taking medication for diabetes. Cardiovascular disease included reporting having angina, heart attack, heart failure, stroke, transient ischemic attack, intermittent claudication, arterial embolism, or deep venous thrombosis. High cholesterol was based on the participant self-reporting that they had high cholesterol or if they were taking medication for high cholesterol. Hypertension was identified if the participant self-reported having high blood pressure, took medication for high blood pressure, or if measured systolic blood pressure exceeded 140 mm Hg or diastolic pressure greater than 90 mm Hg. Ototoxic medication use was identified based on currently taking on a regular basis (i.e., daily, weekly, or monthly), but not a course of (i.e., 1 week only), of any medication with a known ototoxic effect, including loop diuretics, aminoglycoside antibiotics, quinine derivatives, nonsteroidal anti-inflammatories, and salicylates.

Noise exposure. Occupational noise exposure was assessed by the question "Have you ever worked in a noisy place where you had to shout to be heard?" Music noise exposure was used as a proxy measure of recreational noise exposure and was assessed by the question "Have you ever listened to music for more than 3 hours per week at a volume which you would need to shout to be heard or, if wearing headphones, someone else would need to shout for you to hear them?" Both questions had the following response options: (a) Yes, for more than 5 years; (b) Yes, for around 1 to 5 years; (c) Yes, for less than 1 year; (d) No; (e) Do not know; or (f) Prefer not to answer. Participants were categorized as *high* exposure if they answered "Yes," irrespective of how long they were exposed, and *low* if they answered "No," for both occupational and music noise exposure separately. This minimum criterion for both occupational- and music-related noise corresponds to exposure exceeding 85 dBA for 8 hr/day (Control of Noise at Work Regulations, 2005), thus ensuring the we were capturing individuals with high levels of noise exposure.

Further information about the assessment procedure can be found at the U.K. Biobank website (http://www.ukbiobank.ac.uk/).

Data Analysis

Analyses were performed using IBM SPSS version 22. The first part of the analysis compared between the industries of interest (Table 1). One-way analysis of variance were used to compare the effect of age and BMI, with industry type as a single between-subjects factor, and Pearson χ^2 tests were used to compare all other categorical variables, including levels of hearing difficulties and tinnitus. Note that there were missing data for some measures (Table 1), most likely due to these measures being added into the U.K. Biobank protocol after data collection for hearing difficulties and tinnitus measures had started, or participants not completing certain questions.

Logistic regression analyses were conducted separately for hearing difficulties and tinnitus to model the effects of industry type, demographic factors (age, sex, SES, and ethnicity), health, and lifestyle factors (BMI, smoking status, alcohol consumption, diabetes, cardiovascular disease, hypertension, cholesterol, physical activity, and ototoxic medication) and noise exposure (occupational and music). In the first iteration of each of these regression models, only industry type was included in the analysis. Demographic factors were then added into the second iteration of the models, and health and lifestyle factors into the third iteration. Occupational and music noise exposures were then factored into the fourth and final iterations of each of the models. With each new iteration, the step change in the omnibus test of model coefficients (χ^2) determined whether the additional factors led to a significant improvement in the model prediction.

For each iteration of the logistic regression model, an overall measure of the percentage accuracy in classification for hearing difficulties and tinnitus is provided. The amount of variance explained by each model iteration (equivalent to R^2 in multiple regression) is given by a pseudo-R^2 value (Nagelkerke R^2), with higher values indicating that a larger proportion of the variance of the dependent variable can be accounted for by the independent (predictor) variables.

Logistic regression models provide odds ratios (ORs), which are measures of the likelihood of the dependent variable (e.g., hearing difficulties) occurring for a given independent variable (e.g., industry type). An OR greater than 1 indicates an increased likelihood of the dependent variable occurring for a given independent variable, whereas an OR less than 1 indicates a decreased likelihood of the dependent variable occurring. For categorical variables, one group within each category is chosen as the control group with which to compare all other categories. For example, for the analysis of industry type, the finance industry was selected as the control group to compare with the other high-risk industries. Wald χ^2 tests provide a measure of whether the OR is significantly greater than—or less than—1 at the level of $\alpha = .05$. If the 95% confidence interval (CI) for the OR includes the value of 1, then the Wald χ^2 statistic will be nonsignificant. For each iteration of the regression model, a convergence of the OR toward 1 (i.e., toward nonsignificance) for high-risk industries versus finance indicates that other predictor variables (i.e., demographic, health and lifestyle, noise exposure) are accounting for the levels of hearing difficulties or tinnitus between these industries.

Results

Descriptive Statistics

For the comparison between industries, there were significant differences for all variables ($p < .001$; Table 1), except ototoxic medications ($p = .05$) and diabetes ($p = .02$; Bonferroni-corrected α level for multiple corrections = .001). For example, the agricultural industry had the oldest workers on average, had the highest proportion of people reporting White ethnic background, and had the highest levels of hearing difficulties. The construction industry had the highest proportion of males, the highest levels of chronic health conditions, and the highest levels of occupational noise exposure. Hearing difficulties were relatively low in the music industry, but also had the lowest SES (i.e., least affluent), highest levels of music noise exposure, and the highest levels of tinnitus. The finance industry had the highest proportion of females, the highest SES (i.e., most affluent), and the lowest levels of noise exposure.

Hearing Function

In the first iteration of the logistic regression model (Table 2), the overall model prediction was significant, $\chi^2(3) = 27.83$, $p < .001$. The model explained 1.11% of the variance (Nagelkerke R^2) in hearing difficulties, and the overall correct classification for hearing difficulties was 91.24%. Industry type was a significant correlate of hearing difficulties ($p < .001$). Agricultural (OR: 1.63, 95% CI [1.18, 2.27]) and construction industry workers (OR: 1.60, 95% CI [1.31, 1.94]) were more likely to have hearing difficulties compared with finance. There was no significant difference between music and finance industries (OR: 0.59, 95% CI [0.24, 1.46]).

In the second iteration, the addition of demographic factors (age, gender, ethnicity, and SES) produced a significant increase in the overall model prediction compared with the first iteration, $\chi^2(6) = 251.51$, $p < .001$. The model explained 10.86% of the variance in hearing difficulties, and the overall correct classification for hearing difficulties was 91.25%. With these additional demographic factors, industry type remained a significant correlate of hearing difficulties ($p < .001$). The odds of having a hearing difficulty in the agricultural industry compared with finance increased (OR: 1.79, 95% CI [1.27, 2.52]), whereas the odds for the construction industry workers compared with finance slightly decreased (OR: 1.58, 95% CI [1.26, 1.97]). The odds of hearing difficulties in the music industry compared with finance reduced further, but there was no significant difference between these industries (OR: 0.57, 95% CI [0.23, 1.43]). Ethnicity was associated with hearing difficulties, with those reporting non-White ethnic background having a much higher probability of having hearing difficulties compared with those who reported White ethnic background (OR: 3.32, 95% CI [2.41, 4.58]), when accounting for all variables.

Health and lifestyle factors (BMI, smoking status, alcohol consumption, diabetes, cardiovascular disease, hypertension, cholesterol, physical activity, and ototoxic medication) were added in the third iteration of the model. The addition of these factors did not improve the overall model prediction, $\chi^2(10) = 11.99$, $p = .29$, and none of these individual lifestyle factors were significant correlates of hearing difficulties. Industry type remained a significant correlate of hearing difficulties ($p < .001$), and the addition of these factors caused a minor increase in the odds of having hearing difficulties in the agricultural industry (OR: 1.81, 95% CI [1.28, 2.55]), a minor decrease in the construction industry (OR: 1.56, 95% CI [1.25, 1.96]), and no change in the music industry compared with the finance industry.

In the final iteration of the regression model, the addition of occupational and music noise exposure produced a significant increase in the overall model prediction, $\chi^2(2) = 6.55$, $p = .04$. The model explained 11.56% of the variance in hearing difficulties, and the overall correct classification for hearing difficulties was 91.20%. This final model iteration caused a decrease in the odds of having hearing difficulties in the agricultural industry (OR: 1.68, 95% CI [1.19, 2.38]) and construction industry (OR: 1.42, 95% CI [1.11, 1.80]) compared with finance. There was also a further decrease in the odds of having hearing difficulties in the music industry compared with finance (OR: 0.51, 95% CI [0.20, 1.28]), but this difference between these industries was not significant. Industry type remained a significant correlate of hearing difficulties ($p = .001$), even when accounting for all of these additional factors. Occupational noise exposure was a significant correlate of hearing difficulties, with exposed individuals being more likely to have hearing difficulties than those who were not exposed (OR: 1.33, 95% CI [1.05, 1.68]). However, music noise exposure was not a significant correlate of hearing difficulties (OR: 1.17, 95% CI [0.83, 1.50]).

Tinnitus

In the first iteration of the logistic regression model (Table 3), the overall model prediction was significant, $\chi^2(3) = 35.97$, $p < .001$. The model explained 1.11% of the variance (Nagelkerke R^2) in tinnitus prevalence, and the overall correct classification for tinnitus was 83.53%. Industry type was a significant correlate of levels of reported tinnitus ($p < .001$). The odds of reported tinnitus were significantly greater in the music (OR: 1.99, 95% CI [1.29, 3.05]) and construction industries (OR: 1.53, 95% CI [1.32, 1.78]) compared with the finance industry. The agricultural industry showed slightly higher odds of reported tinnitus than finance, but this difference was not significant (OR: 1.18, 95% CI [0.90, 1.54]).

The addition of demographic factors in the second iteration of the model significantly improved the overall model prediction of tinnitus prevalence, $\chi^2(6) = 91.77$, $p < .001$, and accounted for 3.73% of the overall variance. The overall correct classification of tinnitus stayed at 83.53%. Industry type remained a significant correlate of levels of tinnitus after including demographic factors ($p < .001$). The music industry (OR: 1.94, 95% CI [1.26, 3.01]) and construction industry (OR: 1.39, 95% CI [1.18, 1.64]) were more likely to report tinnitus than the finance industry, but the odds were reduced with the addition of these demographic factors. There was no significant difference between agricultural and finance industries, but the odds of reported tinnitus were also slightly reduced in the agricultural industry (OR: 1.13, 95% CI [0.86, 1.49]). Age was a significant correlate of tinnitus, with a 4% increase in the

Table 2. Logistic Regression Model for Hearing Difficulties With Industry Type, Demographic, Health, and Lifestyles Factors, and Noise Exposure.

	Step 1				Step 2				Step 3				Step 4			
	$\chi^2(3) = 27.83$, $p < .001$; $R^2 = .01$				$\chi^2(6) = 251.51$, $p < .001$; $R^2 = .11$				$\chi^2(10) = 11.99$, $p = .29$; $R^2 = .11$				$\chi^2(2) = 6.55$, $p = .04$; $R^2 = .12$			
			95% CI				95% CI				95% CI				95% CI	
Factors	Wald χ^2	OR	Lower	Upper	Wald χ^2	OR	Lower	Upper	Wald χ^2	OR	Lower	Upper	Wald χ^2	OR	Lower	Upper
Industry type																
Industry (vs. finance)	27.31***	–	–	–	24.17***	–	–	–	23.67***	–	–	–	16.26**	–	–	–
Agricultural	8.53**	1.63	1.18	2.27	11.23***	1.79	1.27	2.52	11.38***	1.81	1.28	2.55	8.57**	1.68	1.19	2.38
Construction	21.59***	1.60	1.31	1.94	15.78***	1.58	1.26	1.97	15.04***	1.56	1.25	1.96	8.03**	1.42	1.11	1.80
Music	1.32	.059	0.24	1.46	1.44	0.57	0.23	1.43	1.44	0.57	0.23	1.43	2.05	0.51	0.20	1.28
Demographic factors																
Age					173.46***	1.10	1.08	1.11	147.30***	1.10	1.08	1.11	148.03***	1.10	1.08	1.12
Gender (vs. female)					0.44	0.92	0.72	1.18	0.38	0.93	0.72	1.19	0.94	0.88	0.69	1.14
Ethnicity (vs. White)					53.65***	3.32	2.41	4.58	50.59***	3.35	2.40	4.68	51.21***	3.38	2.42	4.72
Townsend (vs. most affluent)					17.33***	–	–	–	15.79**	–	–	–	14.87**	–	–	–
Second quartile					2.95	1.27	0.97	1.67	2.90	1.27	0.97	1.67	2.80	1.26	0.96	1.66
Third quartile					11.28***	1.59	1.21	2.08	10.55**	1.57	1.19	2.05	9.87**	1.54	1.18	2.02
Most deprived					13.88***	1.72	1.29	2.29	12.60***	1.69	1.26	2.25	12.00***	1.67	1.25	2.23
Lifestyle factors																
Smoking status (vs. nonsmoker)									4.74	–	–	–	3.89	–	–	
Current smoker									4.28*	1.42	1.02	1.97	3.57	1.38	0.99	1.90
Previous smoker									1.54	1.14	.93	1.41	1.18	1.12	0.91	1.39
Alcohol drinker (vs. nondrinker)									0.03	0.97	0.66	1.41	0.03	0.97	0.66	1.42
BMI									1.71	0.98	0.96	1.01	2.01	0.98	0.96	1.01
Diabetes (vs. no)									0.14	0.92	0.60	1.41	0.11	0.93	0.61	1.43
Cardiovascular disease (vs. no)									0.01	1.02	0.73	1.42	0.03	1.03	.74	1.44
High cholesterol (vs. low)									0.50	1.10	0.85	1.42	0.44	1.09	0.84	1.41
Hypertension (vs. no)									0.69	0.91	0.74	1.13	0.69	0.91	0.74	1.13
Physically inactive (vs. active)									0.65	1.09	0.88	1.34	0.76	1.10	0.89	1.35
Ototoxic medication (vs. no)									2.53	1.19	0.96	1.46	2.30	1.18	0.95	1.45
Noise exposure																
Work noise exposure (vs. low)													.5.58*	1.33	1.05	1.68
Music noise Exposure (vs. low)													0.53	1.17	0.83	1.50
Constant	1,394.72***	0.08	–	–	354.53***	2.50×10^{-4}	–	–	166.13***	3.63×10^{-4}	–	–	165.59***	3.40×10^{-4}	–	–

Note. Total: $n = 5{,}603$; agricultural: $n = 425$, construction: $n = 1{,}871$, music: $n = 114$, finance: $n = 3{,}193$. BMI = body mass index; CI = confidence interval.
$^{*}p < .05$. $^{**}p < .01$. $^{***}p < .001$.

Table 3. Logistic Regression Model for Tinnitus With Industry Type, Demographic, Health, and Lifestyles Factors, and Noise Exposure.

	Step 1				Step 2				Step 3				Step 4			
	$\chi^2(3) = 35.97$, $p < .001$; $R^2 = .01$				$\chi^2(6) = 91.77$, $p < .001$; $R^2 = .04$				$\chi^2(10) = 9.10$, $p = .52$; $R^2 = .04$				$\chi^2(2) = 56.17$, $p < .001$; $R^2 = .06$			
			95% CI				95% CI				95% CI				95% CI	
Factors	Wald χ^2	OR	Lower	Upper	Wald χ^2	OR	Lower	Upper	Wald χ^2	OR	Lower	Upper	Wald χ^2	OR	Lower	Upper
Industry type																
Industry (vs. finance)	39.54***	–	–	–	21.55***	–	–	–	20.54***	–	–	–	4.10	–	–	–
Agricultural	1.35	1.18	0.90	1.54	0.75	1.13	0.86	1.49	0.61	1.12	0.85	1.47	0.05	0.97	0.73	1.28
Construction	31.16***	1.53	1.32	1.78	15.75***	1.39	1.18	1.64	14.81***	1.38	1.17	1.63	2.15	1.14	.96	1.37
Music	9.75**	1.99	1.29	3.05	8.86**	1.94	1.26	3.01	8.60**	1.93	1.24	2.99	2.06	1.39	.89	2.19
Demographic factors																
Age					71.12***	1.04	1.03	1.05	60.87***	1.04	1.03	1.05	76.48***	1.05	1.04	1.06
Gender (vs. female)					3.14	1.18	.98	1.41	4.18*	1.21	1.01	1.45	.78	1.09	.90	1.31
Ethnicity (vs. White)					1.13	0.83	0.59	1.17	0.92	.084	0.60	1.19	0.86	0.85	0.60	1.20
Townsend (vs. most affluent)					4.48	–	–	–	4.76	–	–	–	5.2	–	–	–
Second quartile					0.01	1.01	0.84	1.22	1.70×10^{-3}	1.00	0.83	1.21	1.65×10^{-4}	1.00	.83	1.21
Third quartile					1.30	1.12	0.92	1.35	1.18	1.11	0.92	1.34	0.70	1.09	0.90	1.32
Most deprived					1.26	0.88	0.71	1.10	1.53	0.87	0.70	1.08	2.39	.84	0.67	1.05
Lifestyle factors																
Smoking status (vs. nonsmoker)									4.88	–	–	–	2.98	–	–	–
Current smoker									0.20	1.06	0.82	1.37	2.66×10^{-3}	0.99	0.77	1.29
Previous smoker									4.87*	1.19	1.02	1.39	2.73	1.14	0.98	1.33
Alcohol drinker (vs. nondrinker)									1.09	0.85	0.62	1.15	1.22	0.84	0.62	1.14
BMI									1.13	0.99	0.97	1.01	1.75	0.99	0.97	1.01
Diabetes (vs. no)									0.18	0.93	0.65	1.38	0.12	0.94	0.65	1.35
Cardiovascular disease (vs. no)									0.12	0.95	0.72	1.26	0.11	0.95	0.72	1.26
High cholesterol (vs. low)									0.60	0.92	0.75	1.13	0.60	0.92	0.75	1.14
Hypertension (vs. no)									0.38	0.95	0.81	1.11	0.39	0.95	0.81	1.11
Physically inactive (vs. active)									5.27×10^{-3}	1.01	0.86	1.18	0.07	1.02	0.87	1.20
Ototoxic medication (vs. no)									0.78	1.07	0.92	1.25	0.42	1.05	0.90	1.23
Noise exposure																
Work noise exposure (vs. low)													27.07***	1.60	1.34	1.91
Music noise exposure (vs. low)													23.12***	1.62	1.33	1.98
Constant	1,287.83***	.16	–	–	219.26***	.02	–	–	80.89***	.02	–	–	90.01***	.02	–	–

Note. Total: $n = 5{,}727$; agricultural: $n = 439$, construction: $n = 1{,}914$, music: $n = 118$, finance, $n = 3{,}256$. BMI = body mass index; CI = confidence interval.
*$p < .05$. **$p < .01$. ***$p < .001$.

probability of reported tinnitus with each year of age (OR: 1.04, 95% CI [1.03, 1.05]).

The addition of health and lifestyle factors in the third iteration did not improve the overall model prediction, $\chi^2(10) = 9.10$, $p = .52$. The correct classification of tinnitus was 8.45%, and accounted for 3.99% of the variance. None of the health and lifestyle factors were significant correlates of tinnitus (all $p > .05$). Industry type remained a significant correlate of tinnitus ($p < .001$). There was a negligible change in the odds of reported tinnitus in music, construction and agricultural industries compared with finance with the addition of these factors. Age remained a significant correlate of tinnitus, and gender was also a significant predictor with the addition of these health and lifestyle factors, with males having greater odds of reported tinnitus compared with females (OR: 1.21, 95% CI [1.01, 1.45]).

In the final iteration, noise exposure increased the overall model prediction, $\chi^2(2) = 56.17$, $p < .001$, and accounted for 5.60% of the variance in tinnitus. The overall correct classification of tinnitus was 83.53%. Industry type was no longer a significant correlate of tinnitus ($p = .25$). There was a reduction in the odds of reported tinnitus in music (OR: 1.39, 95% CI [0.89, 2.19]), construction (OR: 1.14, 95% CI [0.96, 1.37]), and agricultural (OR: 0.97, 95% CI [0.73, 1.28]) industries compared with finance, and there was no significant differences between high- and low-risk industries (all $p > .05$). Age remained a significant correlate of tinnitus, while both occupational (OR: 1.60, 95% CI [1.34, 1.91]) and music noise exposure (OR: 1.62, 95% CI [1.33, 1.98]) increased the probability of reported tinnitus.

Discussion

We aimed to determine the extent to which occupational noise exposure versus demographic, health, and lifestyle factors might account for higher levels of hearing difficulties and tinnitus in high noise exposure industries (agricultural, construction, and music) compared with an industry with low noise exposure (finance). Data for a large participant sample were obtained from the U.K. Biobank resource. Hearing difficulties were more common in the agricultural and construction industries compared with the finance industry, and tinnitus was more common in construction and music industries compared with finance. Occupational noise exposure, older age, low SES, and non-White ethnic background partially accounted for higher levels of hearing difficulties in the construction industry compared with the finance industry. Occupational noise exposure alone partially accounted for higher levels of hearing difficulties in the agricultural industry compared with finance. However, the predictors of hearing difficulties included in the model did not fully account for the increased likelihood of hearing difficulties in these high-risk industries. Higher levels of tinnitus in music and construction industries compared with finance were accounted for by occupational and music noise exposure, as well as older age. These findings are discussed in detail below.

Prior to accounting for demographic, health, lifestyle, and noise exposure factors, construction and agricultural industries were found to have higher odds of hearing difficulties than the finance industry; in accordance with previous research (Nelson et al., 2005; Sliwinska-Kowalska & Davis, 2012; Stucken & Hong, 2014; Tak et al., 2009). Farming is one of the highest ranked occupations at a risk of hearing loss due to the high levels of noise exposure (Milz et al., 2008), exposure to farming-related noise from an early age (Ehlers & Graydon, 2011; Renick, Crawford, & Wilkins, 2009), and relatively low uptake of hearing protection devices (Depczynski, Challinor, & Fragar, 2011; McCullagh, Banerjee, Cohen, & Yang, 2016; McCullagh, Lusk, & Ronis, 2002). Hearing protection use in the construction industry has become more ubiquitous in the past 30 to 40 years (NIOSH, 1998; Rabinowitz, Galusha, Dixon-Ernst, Clougherty, & Neitzel, 2013), which could explain why the levels of hearing difficulties were found to be slightly lower than the agricultural industry in the current study.

For the construction industry, the addition of demographic factors in the second step of the regression model lead to a slight reduction in the likelihood of hearing impairment compared with the first step. This suggests that demographic factors such as increasing age, non-White ethnic background, and lower SES may also contribute to higher levels of hearing impairment in construction compared with the finance industry. For the agricultural industry, the addition of demographic factors caused an *increase* in the likelihood of hearing difficulties, therefore demographic factors were less able to account for differences in hearing difficulties compared with the finance industry. This could be due to the agricultural industry having a higher proportion of people reporting White ethnic background than other professions (Table 1), with those reporting White ethnic background being less likely to have a hearing difficulty compared with non-White ethnic background in the current analysis. The finding of lower levels of hearing difficulties among those reporting majority White British ethnic background than in those reporting non-White ethnic background is in accordance with previous U.K. Biobank studies (e.g., Dawes, Fortnum, et al., 2014). In these previous studies, high levels of hearing problems were observed for particular non-White ethnic groups that tend to experience the highest levels of deprivation (Dawes, Fortnum, et al., 2014). These particular U.K. ethnic groups also tend to have the poorest health outcomes more generally (Department of Health, 2001).

Previous research in the United States reported that non-White ethnicity was associated with *reduced* risk of hearing loss (Agrawal et al., 2008). The explanation offered for better hearing among U.S. non-White ethnic groups was related to protective effects of melanin in the cochlea (Barrenäs & Lindgren, 1991). It may be that in the United Kingdom, factors associated with deprivation in particular ethnic minority groups might outweigh any biological resilience to NIHL conveyed by high levels of cochlear melanin.

Construction and agricultural industry workers remained at higher risk of hearing difficulties compared with finance after accounting for noise exposure and all demographic, health, and lifestyle factors. Occupational noise exposure, increasing age, ethnicity, and low SES may therefore only partially account for the higher risk of hearing difficulties in the construction industry compared with finance, and occupational noise exposure alone partially accounts for the higher risk in the agricultural industry. This could mean that (a) there are other unknown or unmeasured factors that could explain differences in hearing difficulties between high- and low-risk industries (e.g., occupation-related exposure to toxic substances that impact hearing; Rybak, 1992) and/or (b) measures included in the current analysis were not fully capturing the impact on hearing (e.g., noise exposure; see section Limitations).

The music industry workers did not have a greater likelihood of having hearing difficulties compared with the finance industry. Instead, this study showed a trend for *lower* levels of hearing difficulties in the music industry compared with finance. These findings are contrary to predictions, given that NIHL in musicians is well-documented (Jansen et al., 2009; Phillips, Henrich, & Mace, 2010; Pouryaghoub, Mehrdad, & Pourhosein, 2017; Sataloff, 1991). Nevertheless, there is also evidence to suggest that musicians may be less susceptible to the effects of noise damage on hearing as nonmusicians (Parbery-Clark, Anderson, & Kraus, 2013). This could be due to musicians having better *listening* abilities compared with nonmusicians, which could counteract the effects of noise exposure. For example, musical training could lead to enhanced auditory perception, working memory, and attention, which may improve performance on speech-in-noise tasks (for recent review, see Coffey, Mogilever, & Zatorre, 2017). This could have been true for musicians undertaking the DIN test in the U.K. Biobank protocol.

Industry type was also found to be a significant correlate of tinnitus, with higher levels of tinnitus in music and construction industries compared with finance. The addition of demographic factors in the second step of the regression model caused a decrease in the likelihood of tinnitus in high-risk industries. In particular, older age may account for some of the differences in likelihood of tinnitus between high- and low-risk industries. Crucially, after accounting for occupational and music noise exposure, as well as all demographic, and health and lifestyle factors in the regression model, industry type was not a significant correlate of tinnitus, and there were no significant differences in the likelihood of tinnitus between high- and low-risk industries. This suggests that both occupational and music noise exposure may account for the differences in the greater odds of having tinnitus in music and construction industries compared with finance, with older age in music and construction industry workers also partially accounting for this finding.

It is unclear why the agricultural industry workers did not have greater odds of tinnitus compared with the finance industry, especially given that agricultural workers had a greater probability of having hearing difficulties. This finding could be due to slightly lower levels of occupational and music noise exposure among agricultural workers compared with music and construction industries. This emphasizes the contribution of factors other than noise exposure (i.e., demographic factors) in explaining the differences in hearing difficulties between industries.

Health and lifestyle factors including smoking, hypertension, and cardiovascular disease were highest in agricultural and construction industries, while high BMI and physical inactivity were greatest in the finance industry. One might expect that these differences in health and lifestyle factors between industries may have had opposing effects on hearing across industries. But these health and lifestyle factors were not significant correlates of hearing difficulties and tinnitus, and their inclusion did not significantly improve the overall model predictions, and so they may not be able to explain differences in hearing difficulties and tinnitus between industries.

Limitations

The response rate to the U.K. Biobank invitation was 5.5%, and the resulting participant sample was generally healthier and of higher SES than the general population; a "healthy volunteer" selection bias (Fry et al., 2017). Therefore, the subsample of U.K. Biobank participants included in this study may not be representative of the general population and may not provide representative hearing impairment and tinnitus rates. Selection bias (or collider bias) can also induce a distorted association between predictor and outcome variables (e.g., lifestyle and hearing impairment), and thus exposure–disease relationships may not be generalizable and should be treated with caution (Cole et al., 2010; Elwert & Winship, 2014).

In the U.K. Biobank protocol, noise exposure was measured using nonstandardized self-reports that do not provide accurate estimates of noise intensity, noise type, and length of exposure. For example, the "shout to be heard" criterion is more likely to correspond to ≥99 dB (see Lutman & Spencer, 1991), so there may be cases of occupational noise exposure that are not captured by this criterion (i.e., 85–98 dB), and only workers with the highest levels of noise exposure may have been identified. As such, it is difficult to precisely determine the effects of noise exposure on hearing difficulties across different industries. It is possible that the similar levels of hearing difficulties between music and finance industries is because the majority of musicians' occupational noise exposure contains less harmful music-related activities (Grinn, Wiseman, Baker, & Le Prell, 2017; le Clercq, van Ingen, Ruytjens, & van der Schroeff, 2016; Valderrama et al., 2018; Yeend, Beach, Sharma, & Dillon, 2017). In contrast, construction and agricultural industries have more damaging impulse sounds (Bramhall, Konrad-Martin, McMillan, & Griest, 2017; Depczynski, Franklin, Challinor, Williams, & Fragar, 2005; Starck, Toppila, & Pyykkö, 2003; Suvorov et al., 2001), and fewer silent periods and less variation in sound levels (Rawool, 2011). Furthermore, music noise exposure may not fully account for the level of recreational noise exposure more generally. Although it is difficult to get a precise measure of lifetime noise exposure, there have been recent developments in self-report measures. The Noise Exposure Structured Interview (Guest et al., 2018) gathers comprehensive estimates of occupational and recreational noise exposure, including a broader estimate of noise intensity using a speech communication table ranging from "Normal voice" (<80 dB) to "Shout in listeners ear" (>110 dB), as well as estimating the length of exposure. Future prospective studies would benefit from a more inclusive and accurate measure of occupational *and* recreational noise exposure, with the latter not limited to music activities.

A further limitation of the U.K. Biobank protocol is that information relating to occupation title was only collected for individuals who were currently employed or self-employed, and previous job history was not recorded. Therefore, participants may have reported occupational noise exposure relating to a previous occupation in a high-risk industry (e.g., construction) but not related to their current occupation which may be in a low-risk industry (e.g., finance). It was not possible to test the extent to which noise exposure from previous occupations relates to current hearing status. Nevertheless, the noise exposure questions do enquire about the history of noise exposure in both occupational and music settings, and so if a participant had previous experience of a noisy occupation or exposure to loud music, then these data would be captured and included in the analysis.

There could also be other factors linked with hearing difficulties and tinnitus which could explain differences between industries, but were not available to be included in the current analysis, such as exposure to chemical contaminants (Rybak, 1992). These additional factors may account for more of the variance in hearing difficulties and tinnitus, where the factors included in the current analysis only explained a small proportion of the variance.

Implications

These findings emphasize the importance of limiting occupational and recreational noise exposure for high-risk occupations such as in agricultural, construction, and music industries. Hearing conservation programs and legislative changes may be effective in isolating or reducing the noise source, increasing the use of hearing protection, and reducing hearing difficulties in high-risk industries (NIOSH, 1998; Rabinowitz et al., 2013; Reddy, Welch, Ameratunga, & Thorne, 2017; Seixas et al., 2011), but there may still be some way to go in improving these hearing conservation programs (Barlow & Castilla-Sanchez, 2012; Daniell et al., 2006; El Dib, Mathew, & Martins, 2012; Lusk et al., 1999; Neitzel & Seixas, 2005; O'Brien, Ackermann, & Driscoll, 2014; Zhao et al., 2012). Based on the current findings, one possibility to improve the efficiency of interventions to promote hearing health is to focus on high-risk demographic subgroups (e.g., lower SES, older individuals, and certain ethnic groups) within industries which have a higher risk of hearing difficulties or tinnitus.

Conclusions

The likelihood of having a hearing difficulty as assessed by a speech-in-noise test was greater for construction and agricultural industries compared with finance. A combination of occupational noise exposure, older age, low SES, and non-White ethnic background partially explain differences in the risk of hearing difficulties between industries. Tinnitus was more commonly reported in music and construction industries compared with finance, and these differences were explained by occupational and music noise exposure, and older age. These findings highlight the importance of legislation to regulate noise exposure limits for professions with high levels of occupational noise exposure. There is a need for interventions to promote healthy hearing in both occupational and recreational settings with a focus on particular demographic subgroups who might be more susceptible to hearing difficulties and tinnitus.

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Supplemental Material

Supplemental material for this article is available online.

References

Agrawal, Y., Platz, E. A., & Niparko, J. K. (2008). Prevalence of hearing loss and differences by demographic characteristics among US adults: Data from the National Health and Nutrition Examination Survey, 1999–2004. *Archives of Internal Medicine*, *168*(14), 1522. doi:10.1001/archinte.168.14.1522

Allen, N., Sudlow, C., Downey, P., Peakman, T., Danesh, J., Elliott, P., ... Collins, R. (2012). UK Biobank: Current status and what it means for epidemiology. *Health Policy and Technology*, *1*(3), 123–126. doi:10.1016/J.HLPT.2012.07.003

Barlow, C., & Castilla-Sanchez, F. (2012). Occupational noise exposure and regulatory adherence in music venues in the United Kingdom. *Noise and Health*, *14*(57), 86. doi:10.4103/1463-1741.95137

Barrenäs, M.-L., & Lindgren, F. (1991). The influence of eye colour on susceptibility to TTS in humans. *British Journal of Audiology*, *25*(5), 303–307. doi:10.3109/03005369109076602

Bramhall, N. F., Konrad-Martin, D., McMillan, G. P., & Griest, S. E. (2017). Auditory brainstem response altered in humans with noise exposure despite normal outer hair cell function. *Ear and Hearing*, *38*(1), e1–e12. doi:10.1097/AUD.0000000000000370

Coffey, E. B. J., Mogilever, N. B., & Zatorre, R. J. (2017). Speech-in-noise perception in musicians: A review. *Hearing Research*, *352*, 49–69. doi:10.1016/J.HEARES.2017.02.006

Cole, S. R., Platt, R. W., Schisterman, E. F., Chu, H., Westreich, D., Richardson, D., ... Poole, C. (2010). Illustrating bias due to conditioning on a collider. *International Journal of Epidemiology*, *39*(2), 417–420. doi:10.1093/ije/dyp334

Collins, R. (2012). What makes UK Biobank special? *The Lancet*, *379*(9822), 1173–1174. doi:10.1016/S0140-6736(12)60404-8

Control of Noise at Work Regulations. (2005). *The control of noise at work regulations 2005*. Retrieved from http://www.legislation.gov.uk/uksi/2005/1643/pdfs/uksi_20051643_en.pdf

Cruickshanks, K. J., Klein, R., Klein, B. E., Wiley, T. L., Nondahl, D. M., & Tweed, T. S. (1998). Cigarette smoking and hearing loss: The epidemiology of hearing loss study. *JAMA*, *279*(21), 1715–1719. doi:10.1001/jama.279.21.1715

Cruickshanks, K. J., Tweed, T. S., Wiley, T. L., Klein, B. E. K., Klein, R., Chappell, R., ... Dalton, D. S. (2003). The 5-year incidence and progression of hearing loss. *Archives of Otolaryngology–Head & Neck Surgery*, *129*(10), 1041. doi:10.1001/archotol.129.10.1041

Cruickshanks, K. J., Wiley, T. L., Tweed, T. S., Klein, B. E., Klein, R., Mares-Perlman, J. A., ... Nondahl, D. M. (1998). Prevalence of hearing loss in older adults in Beaver Dam, Wisconsin. The Epidemiology of Hearing Loss Study. *American Journal of Epidemiology*, *148*(9), 879–886. doi:10.1093/oxfordjournals.aje.a009713

Daniel, E. (2007). Noise and hearing loss: A review. *Journal of School Health*, *77*(5), 225–231. doi:10.1111/j.1746-1561.2007.00197.x

Daniell, W. E., Swan, S. S., McDaniel, M. M., Camp, J. E., Cohen, M. A., & Stebbins, J. G. (2006). Noise exposure and hearing loss prevention programmes after 20 years of regulations in the United States. *Occupational and Environmental Medicine*, *63*(5), 343–351. doi:10.1136/oem.2005.024588

Davis, A., McMahon, C. M., Pichora-Fuller, K. M., Russ, S., Lin, F., Olusanya, B. O., ... Tremblay, K. L. (2016). Aging and hearing health: The life-course approach. *The Gerontologist*, *56*(Suppl. 2), S256–S267. doi:10.1093/geront/gnw033

Dawes, P., Cruickshanks, K. J., Moore, D. R., Edmondson-Jones, M., McCormack, A., Fortnum, H., ... Munro, K. J. (2014). Cigarette smoking, passive smoking, alcohol consumption, and hearing loss. *Journal of the Association for Research in Otolaryngology*, *15*(4), 663–674. doi:10.1007/s10162-014-0461-0

Dawes, P., Fortnum, H., Moore, D. R., Emsley, R., Norman, P., Cruickshanks, K., ... Munro, K. (2014). Hearing in middle age: A population snapshot of 40- to 69-year olds in the United Kingdom. *Ear and Hearing*, *35*(3), e44–e51. doi:10.1097/AUD.0000000000000010

Department of Health. (2001). *Health survey for England 1999: The health of minority ethnic groups*. Retrieved from http://webarchive.nationalarchives.gov.uk/+/www.dh.gov.uk/en/Publicationsandstatistics/Publications/PublicationsStatistics/DH_4009393

Depczynski, J., Challinor, K., & Fragar, L. (2011). Changes in the hearing status and noise injury prevention practices of Australian farmers from 1994 to 2008. *Journal of Agromedicine*, *16*(2), 127–142. doi:10.1080/1059924X.2011.554770

Depczynski, J., Franklin, R. C., Challinor, K., Williams, W., & Fragar, L. J. (2005). Farm noise emissions during common agricultural activities. *Journal of Agricultural Safety and Health*, *11*(3), 325–334. doi:10.13031/2013.18575

Dobie, R. A. (2008). The burdens of age-related and occupational noise-induced hearing loss in the United States. *Ear and Hearing*, *29*(4), 565–577. doi:10.1097/AUD.0b013e31817349ec

Dubno, J. R., Dirks, D. D., & Morgan, D. E. (1984). Effects of age and mild hearing loss on speech recognition in noise.

The Journal of the Acoustical Society of America, 76(1), 87–96. doi:10.1121/1.391011
Ehlers, J., & Graydon, P. (2011). Noise-induced hearing loss in agriculture: Creating partnerships to overcome barriers and educate the community on prevention. *Noise and Health*, *13*(51), 142. doi:10.4103/1463-1741.77218
El Dib, R. P., Mathew, J. L., & Martins, R. H. (2012). Interventions to promote the wearing of hearing protection. In R. P. El Dib (Ed.), *Cochrane database of systematic reviews* (CD005234). Chichester, England: John Wiley & Sons, Ltd. doi:10.1002/14651858.CD005234.pub5
Elwert, F., & Winship, C. (2014). Endogenous selection bias: The problem of conditioning on a collider variable. *Annual Review of Sociology*, *40*, 31–53. doi:10.1146/annurev-soc-071913-043455
Fausti, S. A., Wilmington, D. J., Helt, P. V, Helt, W. J., & Konrad-Martin, D. (2005). Hearing health and care: The need for improved hearing loss prevention and hearing conservation practices. *Journal of Rehabilitation Research and Development*, *42*(4 Suppl. 2), 45–62. doi:10.1682/JRRD.2005.02.0039
Fernández, M. D., Quintana, S., Chavarría, N., & Ballesteros, J. A. (2009). Noise exposure of workers of the construction sector. *Applied Acoustics*, *70*(5), 753–760. doi:10.1016/J.APACOUST.2008.07.014
Ferrite, S., & Santana, V. (2005). Joint effects of smoking, noise exposure and age on hearing loss. *Occupational Medicine*, *55*(1), 48–53. doi:10.1093/occmed/kqi002
Fry, A., Littlejohns, T. J., Sudlow, C., Doherty, N., Adamska, L., Sprosen, T., ... Allen, N. E. (2017). Comparison of sociodemographic and health-related characteristics of UK Biobank participants with those of the general population. *American Journal of Epidemiology*, *186*(9), 1026–1034. doi:10.1093/aje/kwx246
Grinn, S. K., Wiseman, K. B., Baker, J. A., & Le Prell, C. G. (2017). Hidden hearing loss? No effect of common recreational noise exposure on cochlear nerve response amplitude in humans. *Frontiers in Neuroscience*, *11*, 465. doi:10.3389/fnins.2017.00465
Guest, H., Dewey, R. S., Plack, C. J., Couth, S., Prendergast, G., Bakay, W., ... Hall, D. A. (2018). The Noise Exposure Structured Interview (NESI): An instrument for the comprehensive estimation of lifetime noise exposure. *Trends in Hearing*, *22*. doi:10.1177/2331216518803213
Heller, A. J. (2003). Classification and epidemiology of tinnitus. *Otolaryngologic Clinics of North America*, *36*(2), 239–248. doi:10.1016/S0030-6665(02)00160-3
Hoffman, H. J., & Reed, G. W. (2004). Epidemiology of tinnitus. In J. B. Snow (Ed.), *Tinnitus: Theory and management* (1st ed., pp. 16–42). Hamilton, ON: BC Decker. Retrieved from https://books.google.co.uk/books?hl=en&lr=&id=BqEq9Re3L5UC&oi=fnd&pg=PA16&ots=elcqnXdBik&sig=ATlGas_HDZ-mZZ9LKwSt7WvK4oU#v=onepage&q&f=false
Hong, O. (2005). Hearing loss among operating engineers in American construction industry. *International Archives of Occupational and Environmental Health*, *78*(7), 565–574. doi:10.1007/s00420-005-0623-9
Jansen, E. J. M., Helleman, H. W., Dreschler, W. A., & de Laat, J. A. P. M. (2009). Noise induced hearing loss and other hearing complaints among musicians of symphony orchestras. *International Archives of Occupational and Environmental Health*, *82*(2), 153–164. doi:10.1007/s00420-008-0317-1
Kerr, M. J., McCullagh, M., Savik, K., & Dvorak, L. A. (2003). Perceived and measured hearing ability in construction laborers and farmers. *American Journal of Industrial Medicine*, *44*(4), 431–437. doi:10.1002/ajim.10286
Le, T. N., Straatman, L. V, Lea, J., & Westerberg, B. (2017). Current insights in noise-induced hearing loss: A literature review of the underlying mechanism, pathophysiology, asymmetry, and management options. *Journal of Otolaryngology—Head & Neck Surgery*, *46*(1), 41. doi:10.1186/s40463-017-0219-x
le Clercq, C. M. P., van Ingen, G., Ruytjens, L., & van der Schroeff, M. P. (2016). Music-induced hearing loss in children, adolescents, and young adults. *Otology & Neurotology*, *37*(9), 1208–1216. doi:10.1097/MAO.0000000000001163
Lie, A., Skogstad, M., Johannessen, H. A., Tynes, T., Mehlum, I. S., Nordby, K.-C., ... Tambs, K. (2016). Occupational noise exposure and hearing: A systematic review. *International Archives of Occupational and Environmental Health*, *89*(3), 351–372. doi:10.1007/s00420-015-1083-5
Lin, F. R., Yaffe, K., Xia, J., Xue, Q.-L., Harris, T. B., Purchase-Helzner, E., ... for the Health ABC Study Group. (2013). Hearing loss and cognitive decline in older adults. *JAMA Internal Medicine*, *173*(4), 293. doi:10.1001/jamainternmed.2013.1868
Lusk, S. L., Hong, O. S., Ronis, D. L., Eakin, B. L., Kerr, M. J., & Early, M. R. (1999). Effectiveness of an intervention to increase construction workers' use of hearing protection. *Human Factors: The Journal of the Human Factors and Ergonomics Society*, *41*(3), 487–494. doi:10.1518/001872099779610969
Lutman, M. E., & Spencer, H. S. (1991). Occupational noise and demographic factors in hearing. *Acta Oto-Laryngologica Supplementum*, *111*(476), 74–84. doi:10.3109/00016489109127258
Marvel, M. E., Pratt, D. S., Marvel, L. H., Regan, M., & May, J. J. (1991). Occupational hearing loss in New York dairy farmers. *American Journal of Industrial Medicine*, *20*(4), 517–531. doi:10.1002/ajim.4700200407
Masterson, E. A., Deddens, J. A., Themann, C. L., Bertke, S., & Calvert, G. M. (2015). Trends in worker hearing loss by industry sector, 1981–2010. *American Journal of Industrial Medicine*, *58*(4), 392–401. doi:10.1002/ajim.22429
Masterson, E. A., Themann, C. L., Luckhaupt, S. E., Li, J., & Calvert, G. M. (2016). Hearing difficulty and tinnitus among U.S. workers and non-workers in 2007. *American Journal of Industrial Medicine*, *59*(4), 290–300. doi:10.1002/ajim.22565
McBride, D., Gill, F., Proops, D., Harrington, M., Gardiner, K., & Attwell, C. (1992). Noise and the classical musician. *British Medical Journal (Clinical Research Ed.)*, *305*(6868), 1561–1563. doi:10.1136/BMJ.305.6868.1561

McBride, D. I., Firth, H. M., & Herbison, G. P. (2003). Noise exposure and hearing loss in agriculture: A survey of farmers and farm workers in the Southland Region of New Zealand. *Journal of Occupational and Environmental Medicine*, *45*(12), 1281–1288. doi:10.1097/01.jom.0000100001.86223.20

McCullagh, M. C., Banerjee, T., Cohen, M. A., & Yang, J. J. (2016). Effects of interventions on use of hearing protectors among farm operators: A randomized controlled trial. *International Journal of Audiology*, *55*(Suppl. 1), S3–S12. doi:10.3109/14992027.2015.1122239

McCullagh, M. C., Lusk, S. L., & Ronis, D. L. (2002). Factors influencing use of hearing protection among farmers: A test of the pender health promotion model. *Nursing Research*, *51*(1), 33–39. doi:10.1097/00006199-200201000-00006

Milz, S. A., Wilkins, J. R., Ames, A. L., & Witherspoon, M. K. (2008). Occupational noise exposures among three farm families in Northwest Ohio. *Journal of Agromedicine*, *13*(3), 165–174. doi:10.1080/10599240802406049

Mizoue, T., Miyamoto, T., & Shimizu, T. (2003). Combined effect of smoking and occupational exposure to noise on hearing loss in steel factory workers. *Occupational and Environmental Medicine*, *60*(1), 56–59. doi:10.1136/OEM.60.1.56

Moore, D. R., Edmondson-Jones, M., Dawes, P., Fortnum, H., McCormack, A., Pierzycki, R. H., ... Munro, K. J. (2014). Relation between speech-in-noise threshold, hearing loss and cognition from 40–69 years of age. *PLoS One*, *9*(9), e107720. doi:10.1371/journal.pone.0107720

National Institute of Occupational Safety and Health. (1998). *Criteria for a recommended standard: Occupational noise exposure, revised criteria 1998*. doi:10.26616/NIOSHPUB98126

Negrila-Mezei, A., Enache, R., & Sarafoleanu, C. (2011). Tinnitus in elderly population: Clinic correlations and impact upon QoL. *Journal of Medicine and Life*, *4*(4), 412–416. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/22514575

Neitzel, R., & Seixas, N. (2005). The effectiveness of hearing protection among construction workers. *Journal of Occupational and Environmental Hygiene*, *2*(4), 227–238. doi:10.1080/15459620590932154

Neitzel, R., Seixas, N. S., Camp, J., & Yost, M. (1999). An assessment of occupational noise exposures in four construction trades. *American Industrial Hygiene Association Journal*, *60*(6), 807–817. doi:10.1080/00028899908984506

Neitzel, R., Stover, B., & Seixas, N. S. (2011). Longitudinal assessment of noise exposure in a cohort of construction workers. *The Annals of Occupational Hygiene*, *55*(8), 906–916. doi:10.1093/annhyg/mer050

Nelson, D. I., Nelson, R. Y., Concha-Barrientos, M., & Fingerhut, M. (2005). The global burden of occupational noise-induced hearing loss. *American Journal of Industrial Medicine*, *48*(6), 446–458. doi:10.1002/ajim.20223

O'Brien, I., Ackermann, B., & Driscoll, T. (2014). Hearing and hearing conservation practices among Australia's professional orchestral musicians. *Noise and Health*, *16*(70), 189. doi:10.4103/1463-1741.134920

Office for National Statistics. (2000). *Standard occupational classification 2000*. Retrieved from https://webarchive.nationalarchives.gov.uk/20160108030321/http://www.ons.gov.uk/ons/guide-method/method-quality/specific/labour-market/soc-2000-and-ns-sec-on-the-lfs/index.html

Parbery-Clark, A., Anderson, S., & Kraus, N. (2013). Musicians change their tune: How hearing loss alters the neural code. *Hearing Research*, *302*, 121–131. doi:10.1016/j.heares.2013.03.009

Patterson, R. D., Nimmo-Smith, I., Weber, D. L., & Milroy, R. (1982). The deterioration of hearing with age: Frequency selectivity, the critical ratio, the audiogram, and speech threshold. *The Journal of the Acoustical Society of America*, *72*(6), 1788–1803. doi:10.1121/1.388652

Pawlaczyk-Łuszczyńska, M., Dudarewicz, A., Zamojska, M., & Śliwinska-Kowalska, M. (2011). Evaluation of sound exposure and risk of hearing impairment in orchestral musicians. *International Journal of Occupational Safety and Ergonomics*, *17*(3), 255–269. doi:10.1080/10803548.2011.11076892

Phillips, S. L., Henrich, V. C., & Mace, S. T. (2010). Prevalence of noise-induced hearing loss in student musicians. *International Journal of Audiology*, *49*(4), 309–316. doi:10.3109/14992020903470809

Pienkowski, M. (2017). On the etiology of listening difficulties in noise despite clinically normal audiograms. *Ear and Hearing*, *38*(2), 135–148. doi:10.1097/AUD.0000000000000388

Pouryaghoub, G., Mehrdad, R., & Pourhosein, S. (2017). Noise-induced hearing loss among professional musicians. *Journal of Occupational Health*, *59*(1), 33–37. doi:10.1539/joh.16-0217-OA

Rabinowitz, P. M., Galusha, D., Dixon-Ernst, C., Clougherty, J. E., & Neitzel, R. L. (2013). The dose–response relationship between in-ear occupational noise exposure and hearing loss. *Occupational and Environmental Medicine*, *70*(10), 716–721. doi:10.1136/oemed-2011-100455

Rawool, V. W. (2011). *Hearing conservation: In occupational, recreational, educational, and home settings* (1st ed.). New York, NY: Thieme Medical Publishers, retrieved from https://www.thieme.com/books-main/audiology/product/1033-hearing-conservation

Reddy, R., Welch, D., Ameratunga, S., & Thorne, P. (2017). An ecological approach to hearing-health promotion in workplaces. *International Journal of Audiology*, *56*(5), 316–327. doi:10.1080/14992027.2016.1271467

Renick, K. M., Crawford, J. Mac, & Wilkins, J. R. (2009). Hearing loss among Ohio farm youth: A comparison to a national sample. *American Journal of Industrial Medicine*, *52*(3), 233–239. doi:10.1002/ajim.20668

Rosenhall, U. (2003). The influence of ageing on noise-induced hearing loss. *Noise & Health*, *5*(20), 47–53. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/14558892

Royster, J. D., Royster, L. H., & Killion, M. C. (1991). Sound exposures and hearing thresholds of symphony orchestra musicians. *The Journal of the Acoustical Society of America*, *89*(6), 2793–2803. doi:10.1121/1.400719

Rybak, L. P. (1992). Hearing: The effects of chemicals. *Otolaryngology-Head and Neck Surgery*, *106*(6), 677–686. doi:10.1177/019459989210600611

Sanchez, L. (2004). The epidemiology of tinnitus. *Audiological Medicine*, *2*(1), 8–17. doi:10.1080/16513860410027781

Sataloff, R. T. (1991). Hearing loss in musicians. *The American Journal of Otology*, *12*(2), 122–127. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/2053603

Schmidt, J. H., Pedersen, E. R., Juhl, P. M., Christensen-Dalsgaard, J., Andersen, T. D., Poulsen, T., … Bælum, J. (2011). Sound exposure of symphony orchestra musicians. *The Annals of Occupational Hygiene*, *55*(8), 893–905. doi:10.1093/annhyg/mer055

Seixas, N. S., Neitzel, R., Stover, B., Sheppard, L., Daniell, B., Edelson, J., … Meischke, H. (2011). A multi-component intervention to promote hearing protector use among construction workers. *International Journal of Audiology*, *50* (Suppl. 1), S46–S56. doi:10.3109/14992027.2010.525754

Seixas, N. S., Neitzel, R., Stover, B., Sheppard, L., Feeney, P., Mills, D., … Kujawa, S. (2012). 10-Year prospective study of noise exposure and hearing damage among construction workers. *Occupational and Environmental Medicine*, *69*(9), 643–650. doi:10.1136/oemed-2011-100578

Sliwinska-Kowalska, M., & Davis, A. (2012). Noise-induced hearing loss. *Noise and Health*, *14*(61), 274–280. doi:10.4103/1463-1741.104893

Smits, C., Kapteyn, T. S., & Houtgast, T. (2004). Development and validation of an automatic speech-in-noise screening test by telephone. *International Journal of Audiology*, *43*(1), 15–28. doi:10.1080/14992020400050004

Starck, J., Toppila, E., & Pyykkö, I. (2003). Impulse noise and risk criteria. *Noise & Health*, *5*(20), 63–73. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/14558894

Stucken, E. Z., & Hong, R. S. (2014). Noise-induced hearing loss. *Current Opinion in Otolaryngology & Head and Neck Surgery*, *22*(5), 388–393. doi:10.1097/MOO.0000000000000079

Suvorov, G., Denisov, E., Antipin, V., Kharitonov, V., Starck, J., Pyykkö, I., … Toppila, E. (2001). Effects of peak levels and number of impulses to hearing among forge hammering workers. *Applied Occupational and Environmental Hygiene*, *16*(8), 816–822. doi:10.1080/10473220119058

Tak, S., Davis, R. R., & Calvert, G. M. (2009). Exposure to hazardous workplace noise and use of hearing protection devices among US workers-NHANES, 1999–2004. *American Journal of Industrial Medicine*, *52*(5), 358–371. doi:10.1002/ajim.20690

Themann, C., Suter, A., & Stephenson, M. (2013). National research agenda for the prevention of occupational hearing loss—Part 1. *Seminars in Hearing*, *34*(3), 145–207. doi:10.1055/s-0033-1349351

Townsend, P., Phillimore, P., & Beattie, A. (1988). *Health and deprivation: Inequality and the north*. London, England: Routledge. Retrieved from https://econpapers.repec.org/RePEc:eee:hepoli:v:10:y:1988:i:2:p:207-206

Tufts, J. B., & Skoe, E. (2018). Examining the noisy life of the college musician: Weeklong noise dosimetry of music and non-music activities. *International Journal of Audiology*, *57* (Suppl. 1), S20–S27. doi:10.1080/14992027.2017.1405289

Valderrama, J. T., Beach, E. F., Yeend, I., Sharma, M., Van Dun, B., & Dillon, H. (2018). Effects of lifetime noise exposure on the middle-age human auditory brainstem response, tinnitus and speech-in-noise intelligibility. *Hearing Research*, *365*, 36–48. doi:10.1016/j.heares.2018.06.003

Verbeek, J. H., Kateman, E., Morata, T. C., Dreschler, W. A., & Mischke, C. (2014). Interventions to prevent occupational noise-induced hearing loss: A Cochrane systematic review. *International Journal of Audiology*, *53*(Suppl. 2), S84–S96. doi:10.3109/14992027.2013.857436

Williams, W., Brumby, S., Calvano, A., Hatherell, T., Mason, H., Mercer-Grant, C., … Hogan, A. (2015). Farmers' work-day noise exposure. *Australian Journal of Rural Health*, *23*(2), 67–73. doi:10.1111/ajr.12153

Yeend, I., Beach, E. F., Sharma, M., & Dillon, H. (2017). The effects of noise exposure and musical training on suprathreshold auditory processing and speech perception in noise. *Hearing Research*, *353*, 224–236. doi:10.1016/j.heares.2017.07.006

Zhao, F., French, D., Manchaiah, V. K., Liang, M., & Price, S. M. (2012). Music exposure and hearing health education: A review of knowledge, attitude, and behaviour in adolescents and young adults. *Health Education Journal*, *71*(6), 709–724. doi:10.1177/0017896911422780

Zhao, F., Manchaiah, V. K. C., French, D., & Price, S. M. (2010). Music exposure and hearing disorders: An overview. *International Journal of Audiology*, *49*(1), 54–64. doi:10.3109/14992020903202520