

## **The effect of occupational noise on hearing-related symptoms - exploring mediating and modifying effect of annoyance and stress**

Sofie Fredriksson<sup>1</sup>, Laith Hussain-Alkhateeb<sup>1</sup>, Kerstin Persson Waye<sup>1</sup>

<sup>1</sup> Occupational and Environmental Medicine, Sahlgrenska Academy, University of Gothenburg, SE-41501, Gothenburg Sweden

Corresponding author's e-mail address: sofie.fredriksson@gu.se

### **ABSTRACT**

Noise-induced hearing disorder is under reported in female-dominated occupations, hindering knowledge on associated risk factors. We performed a cross-sectional study in Sweden, including 4,718 female preschool teachers and 4,122 randomly selected women age 24-65. In hypothesised causal models, we explored the effect of occupational noise exposure (e.g. self-reported retrospective and current exposure, hearing protection) on hearing-related symptoms (hearing loss, speech perception, tinnitus, hyperacusis, sound-induced auditory fatigue). Noise annoyance, job-stress and stress response were assessed for mediating and modifying effects.

Exposure to occupational noise significantly increased the risk of hearing-related symptoms among preschool teachers (RRs 1.19-1.42 in adjusted log-binomial regression models). Consistent with our hypothesis, annoyance mediated the effect of noise exposure on sound-induced auditory fatigue (indirect effect  $\beta=0.28$ ). In contrast, annoyance modified the effect of noise exposure on both hyperacusis and speech perception. For sound-induced auditory fatigue and hyperacusis, job-stress exposure and stress response both modified the effect and significantly interacted with noise exposure. The models provide better understanding of possible mechanisms for developing hearing-related symptoms. These findings will be further explored using longitudinal design.

### **INTRODUCTION**

The preschool work environment concerns a large number of employees in Sweden. In 2014, preschool teacher was the fourth most common occupation among women and at least 95 percent of all preschool teachers are women.

In Sweden, the highest number of work-related disorders due to noise in the female workforce are reported by preschool teachers [1]. Noise exposure in preschool is however not a new work environment problem and not only a concern in Sweden. Numerous studies dating back more than 30 years from various different countries have reported high noise levels in preschools [2-9]. Recent studies from Sweden have reported an average sound level indoors in preschools close to current occupational regulated action level 80 dBA Leq(8h) [7, 9], and up to 100 events per hour exceeding 85 dBA [8].

One major health outcome of high level noise exposure is hearing disorder. However, noise-induced hearing disorder is under reported in female-dominated occupations. Instead, most of research has been performed in traditionally male-dominated occupations where machines and tools are typical noise sources. Most often, these studies have focused on hearing loss as the main outcome. Preschool personnel, however, commonly report children's voices, screams and playing activity as the main source of noise annoyance [7-9]. Less is known of the impact on hearing from communicative and highly intermittent sounds, especially concerning the effect on hearing-related symptoms other than hearing loss. A few studies have shown that preschool personnel commonly report other symptoms such as tinnitus [8], hyperacusis (increased sound sensitivity) [10] and sound-induced auditory fatigue [7]. Generally, a causal effect of noise exposure on hearing loss is well-recognised [11-13]. The causal relationship for noise-induced tinnitus is also rather well established [14, 15], while somewhat less is known of the relationship between noise exposure and hyperacusis [16, 17]. Furthermore, sound-induced auditory fatigue has been described as a sensation of fatigue from within the ear and a need for silence after hours in a communication intense sound environment [7], and has recently been associated to occupational noise exposure among obstetrics personnel exposed to intense screaming [18], but causality has not been assessed.

Noise exposure may also elicit non-auditory effects. Annoyance is a well-described and common reaction to environmental noise, but has also been discussed in relation to occupational exposure and pupils' exposure in school – especially concerning effects on performance [19]. Interestingly, Heinonen-Guzejev et al. depict noise annoyance as a potential mediator on the pathway from noise exposure to health effects in a schematic model of noise sensitivity for the risk of lowered work ability and subsequent disability retirement [20]. Although the possible mediating effect is not discussed in that paper, it is indeed an interesting hypothesis, certainly when assessing annoying noise exposure, which is commonly described as annoying (e.g. irrelevant speech, unpredictable and varying sounds found in the communication intense sound environment). Noise exposure may also act as a stressor, which activates the sympathetic and endocrine system and thus contributes to health outcomes such as cardiovascular disorders [21]. Interestingly, work-related stressors have also been suggested to negatively affect the auditory system [22-24]. The hypothesised mechanisms involve sympathetic stimulation, activation of the hypothalamic–pituitary–adrenal axis [25], with glucocorticoid receptors within the auditory system playing an important role [26]. Evidence is however still weak and causality is not established.

In this analysis we hypothesise that both noise annoyance and stress may be important in the development of hearing-related outcomes among preschool teachers exposed to communication intense occupational noise. Thus, the aim of this analysis was to assess whether noise annoyance, job-stress exposure and stress response mediate or moderate the effect of noise exposure on hearing-related symptoms. Therefore, a hypothesised causal model is assessed among preschool teachers in comparison to a large group of randomly selected population controls.

## **METHODS**

### **Subjects**

A postal questionnaire survey was conducted between October 2013 and July 2014. The questionnaire was sent to individuals with a preschool teachers' degree issued between 1980 and 2012 from universities in the Västtra Götaland county of Sweden, who had a

current postal address (n 11.232). The questionnaire was also sent to randomly selected women in the general population born between 1943 and 1989, currently residing in Västra Götaland County, not already included in the preschool cohort, with current postal address (n 14.524). Response rate was 51% (n 5.687) among preschool teachers and 38% (n 5.480) among controls. The current analysis included women in working age (up to 65 years). Thus, 4.718 preschool teachers and 4.122 controls were analysed.

## Questionnaire

We assessed hearing-related symptoms with questionnaire items which have been used and validated among obstetrics personnel exposed to high sound levels at work [18, 27]: hearing loss, difficulty perceiving speech (both work and leisure time), tinnitus, hyperacusis and sound-induced auditory fatigue. Symptoms were assessed as binary outcomes, with definitions identical to previous analyses [18, 27].

We also assessed noise exposure at work using questionnaire items including degree of exposure, use of hearing protection, change of job due to noise, acoustic interventions and noise annoyance. All items assessed both current workplace and the work held five years earlier. In the statistical analysis, occupational noise exposure was assessed by calculation of a cumulative occupational noise exposure index derived from the exposure items (excluding annoyance). A higher score on the noise index indicate a higher total exposure dose. A previous analyses used a similar method [18]. Noise annoyance was assessed as a binary variable. Annoyance was defined as reporting pretty much, very or extreme annoyance.

Job-stress was assessed both as exposure of stressful working conditions using Effort-Reward Imbalance (ERI) [28], and emotional demands scale from the two-item short-form Copenhagen Psychosocial Questionnaire (COPSOQ) [29], and as stress response using a scale measuring symptoms of long-lasting stress (LLS) [23]. All three were assessed as binary variables. Job-stress measured by ERI was defined as a ratio between effort and reward  $>1$  [28]. Job-stress measured by COPSOQ was defined as responding often or always to both items. Stress response (LLS) was defined as answering pretty often or almost always to at least one of five items.

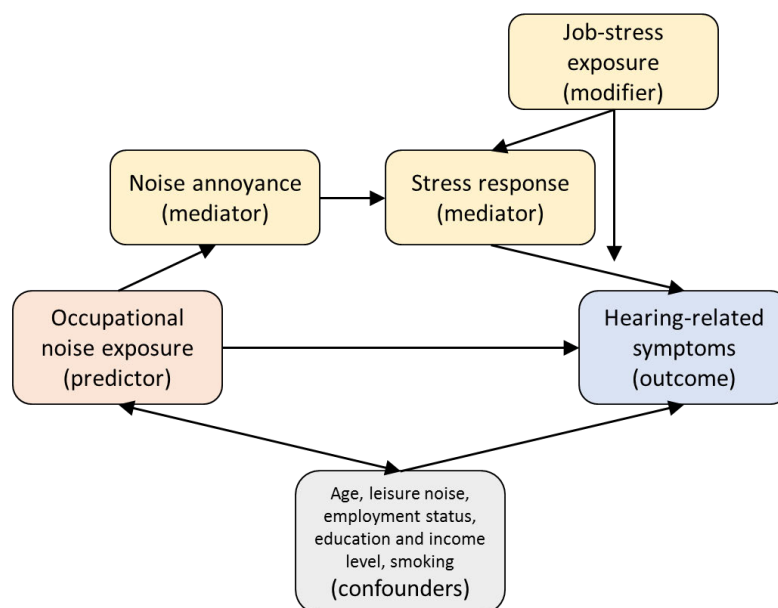
We also included age, employment status, education level, income level, leisure noise and smoking as possible confounders. Leisure noise exposure was assessed as an exposure index similar to the occupational noise index, while the other confounders were assessed as binary variables.

## Statistical analysis

Based on our hypothesised causal model (DAG, direct acyclic graph) shown in figure 1, we assessed whether noise annoyance, job-stress exposure (COPSOQ or ERI) or stress response (LLS) acted as mediators in the relationship between occupational noise exposure and hearing-related symptoms. We employed the *causal steps approach* popularized by Baron and Kenny [30] - the most widely used method - to assess the mediation effect by variables across all five hearing-related outcomes. Each causal path was estimated and further ascertained by measuring certain statistical criteria. These criteria were investigated only when evidence of a total effect in the association was found (i.e. significant effect of exposure on outcome). Full details on how to assess these paths are described elsewhere [31]. Bootstrapping method was followed to produce unbiased standard errors and confidence intervals for examining the indirect, direct and total effects caused by the

mediator. In parallel steps, noise annoyance, job-stress exposure (COPSOQ or ERI) or stress response (LLS) were all checked for moderating effect (i.e. interaction). To assess whether the interaction term was significant, a Wald test was used with a significant level of 5% to reject the null hypothesis (coefficients from stratified associations are simultaneously equal to “zero”). Finally, to explore our hypothesized causal model of hearing-related symptoms among those exposed to occupational noise (preschool teachers) and the assumed exposure-free group (controls), we computed adjusted risk ratios using the log-binomial regression model [32]. The final adjusted model included moderators and mediators from previous steps as well as potential confounders following the forward stepwise approach. The best-fit model was chosen based on the likelihood ratio test. Statistical analyses were performed using STATA (StataCorp, 2015. Release 14.1).

The final best-fit models were then visualised in DAGs for each outcome.



**Figure 1:** DAG showing the conceptual framework and hypothesised model for risk of hearing-related symptoms by exposure of occupational noise with a mediating effect from noise annoyance via stress response, modified by job-stress exposure.

## RESULTS

The resulting models found in our analysis are shown in figure 2 A-E, representing the causal pathways for each outcome with estimates on the indirect effects via mediators and direct effects of occupational noise exposure as well as p-values for the modifying effects.

In line with our hypothesis, noise annoyance mediated the effect of noise exposure on sound-induced auditory fatigue computing an indirect effect of 0.28 (95% CI; 0.26-0.30). Both stress response (LLS) (p-value=0.001) and job-stress exposure (ERI) (p-value=0.001)

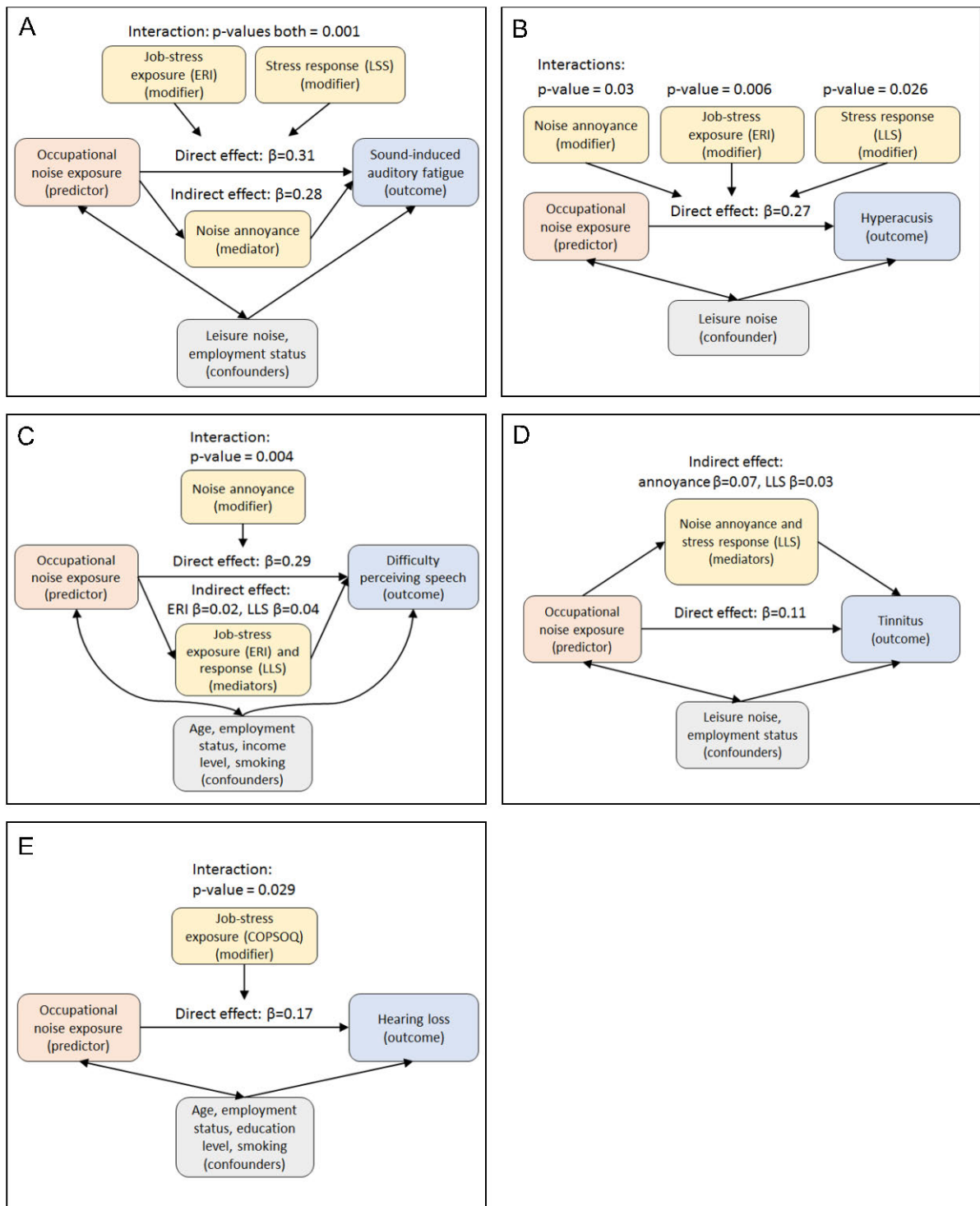
showed a significant modifying effects with occupational noise while adjusting for relevant covaries, see figure 2 A.

On the contrary to our hypothesis, annoyance modified (not mediated) the effect of noise exposure on both hyperacusis (p-value=0.030) and difficulty perceiving speech (p-value=0.004). See figure 2B and 2C. For difficulty perceiving speech, both LLS ( $\beta=0.02$ ; 95% CI: 0.01-0.02) and ERI ( $\beta=0.04$ ; 95% CI: 0.03-0.05) mediated the effect of noise exposure in this association. The indirect effect however, was rather small. For hyperacusis, both LLS and ERI maintained their role as significant moderators (p-value=0.026 and p-value=0.006, respectively).

Furthermore, noise annoyance acted as a partial mediator in the association between tinnitus and noise exposure ( $\beta=0.07$ ; 95% CI: 0.043-0.097) with a similar role observed by the LLS in the same association ( $\beta=0.03$ ; 95% CI: 0.01-0.10). See figure 2D.

Job-stress exposure (COPSOQ) was a significant moderator (p-value=0.029) in the association between hearing loss and noise exposure. None of the other variables contributed to the model. See figure 2E. COPSOQ instead of ERI as a measure of job-stress exposure gave a similar but better model fit for hearing loss, contrarily to the other outcomes where ERI had a better model fit.

Adjusted log-binomial analysis based on the resulting models for each hearing-related outcome demonstrated that exposure to occupational noise significantly increased the risk of hearing-related symptoms among preschool teachers when compared to randomly selected women in the population (controls). The risk ratio (RR) was highest for sound-induced auditory fatigue 1.42 (95% CI: 1.36-1.51), i.e. 42% increased risk for preschool teachers compared to controls. The second highest RR was 1.40 for hyperacusis (95% CI 1.27-1.55) followed by difficulty perceiving speech RR 1.34 (1.22-1.45), hearing loss RR 1.21 (1.06-1.37) and tinnitus RR 1.19 (1.06-1.34).



**Figure 2 A-E:** Resulting models for each hearing-related symptom: Sound-induced auditory fatigue (A), Hyperacusis (B), Difficulty perceiving speech (C), Tinnitus (D) and Hearing loss (E).

## CONCLUDING COMMENTS

The models resulting from the analyses are a first step towards a deeper understanding on how noise exposure, noise annoyance and stress (both as job-stress exposure and as a stress response) are associated to hearing-related symptoms. The analysis indicates that the different symptoms may have different causal mechanisms, which is perhaps not surprising as the symptoms may reflect different underlying auditory disorder and even non-auditory effects. The symptom of hearing loss may for example be more closely related to peripheral injuries (worse hearing thresholds), while sound-induced auditory fatigue may also be a result of impacts along the central auditory pathways, cognitive or mental fatigue.

As the data assessed and discussed here is based exclusively on women, many of which were preschool teachers, the results may be specifically interesting for the type of noise commonly occurring in female-dominated occupations. Our data suggest that noise exposure that bears important information for the worker (such as speech communication) may show a different causal mechanism compared to noise from machines or tools, however this has not been studied in relation to different hearing-related outcomes. The resulting models may therefore be significant for the type of noise exposure many of the women in our data encounter, i.e. communication noise in preschool. In this context, it is interesting to note that two very commonly researched symptoms of noise exposure - hearing loss and tinnitus - show less strong association to noise exposure compared to the other symptoms. This suggests that different types of disorders may have different causes in respect to type or level of noise exposure. The increased risk of hearing related symptoms in general and for sound-induced auditory fatigue and hyperacusis in particular among the preschool teachers further underline the importance of acknowledging communication intense sound environments as risk environments for hearing disorders.

The models presented here provide better understanding of possible mechanisms for developing hearing-related symptoms and further research specifically aimed at assessing these mechanisms in longitudinal designs are proposed as a next step. Improvement of noise assessment using Job Exposure Matrix (JEM) is also planned. In the long term, implication of such studies may show not only causing mechanisms, but also potential interventions. Besides minimising the noise exposure in order to decrease the risk of hearing loss, it may be important to minimise specifically the type of noise causing annoyance in order to decrease the risk for sound-induced auditory fatigue. For many of the symptoms it was also proposed that both job-stress exposure and stress response may have an impact on hearing-related symptoms, as measured here. Thus, in order to assure healthy hearing throughout the working life all these factors may be important in prevention of hearing disorder.

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