Effects of noise sensitivity on sound perception, symptoms and cognition

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EFFECTS OF NOISE SENSITIVITY ON SOUND PERCEPTION, SYMPTOMS AND COGNITION

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Noise sensitivity is a condition characterised by an excessive reaction to harmless levels of sound that would not normally affect typically functioning people. Previous research have found that reactions such as the reduction of attention and concentration as well as the presence of medically unexplained common symptoms such as headaches and fatigue appear in sufferers. The aim of the present study was to investigate whether such a class of sound sensitive individuals are affected by exposure to a potentially unpleasant sound source more than a relatively low sound sensitive group of individuals. Forty adults between 18-54 years of age were exposed to a white noise sound stimulus within a soundproof exposure chamber for 45 minutes. The sound pressure level of the sound varied over the course of the exposure session. The dependent variables of the study were perceived intensity, unpleasantness and effect on concentration, symptoms and cognitive strain. After the exposure session, participants were asked to fill in an online survey that included a 21 item Noise Sensitivity Scale. This was used to group the participants accordingly to a low or high NSS group. The high NSS group compared to the low NSS group had higher ratings for unpleasantness and negative effects on concentration after time point four, at which point the noise stimulus had been introduced. No differences were observed in ratings of Intensity of the noise stimulus between groups. The high NSS group also demonstrated higher ratings for symptoms after the noise stimulus had been introduced. In addition they also demonstrated a lower level of improvement for the cognitive task in comparison to the low NSS group. The findings from this study imply that individuals suffering from hyperacusis can be negatively affected by the presence of annoying sound stimuli. Hyperacusis can mean that sounds can become unpleasant to sufferers as well as potentially affecting their ability to concentrate.

What we would expect to find when observing a typically populated environment is a relatively stable consistency amongst people being able to function and engage in numerous and various day to day tasks and activities adequately well. Despite potential interference made by any number of extraneous disturbances in the background such as sounds, smells, vibrations or light, we might expect that most individuals are able to continue, unhindered, with their tasks. However, what would also be expected is the presence of individuals within the population, who may react more intensely to environmental disturbances at levels typically operating people would consider minute levels (Sorg, 1999).

One explanation for this is the numerous conditions that have been identified over the last decades known in sum as environmental intolerance. Characteristic for environmental intolerance is the display of multisystem symptoms from the exposure of a specific negative environmental stimuli to the sufferer. Examples of some of these symptoms that are typically reported are temporary impairment effects on cognition such as on attention and memory or general complaints on personal well-being such as the present state of headaches, fatigue, nausea, dizziness (Palmer, Claeson, Neely, Stenberg & Nordin, 2014). These symptoms are generally medically unexplained, offering trivial sign of the apparent illness, are nonspecific in nature as well as a portion of the symptoms frequenting certain types of environmental intolerance than others (Palmer et al., 2014).

Of these environmentally intolerant individuals, it could be possible for a group to display an abnormal intolerance to noises and sounds in accordance to the manner that has been described. Particular types of audio or even commonplace environmental sounds such as road traffic noise could be perceived as distinctly more disturbing than how most individuals would ordinarily perceive such sounds (Fyhri & Klaboe, 2009). Among the health complaints expressed by these noise sensitive individuals are more severe complaints concerning their cardiac health. One particular study on noise sensitive individuals found that women generally reported significant cardiovascular mortality in the presence of long term noise exposure (Heinonen-Guzzejev, 2009).

One term for such a class of auditory disorder is known as hyperacusis, which can be described as the phenomenon exhibited in individuals displaying their perception of certain everyday sounds as greatly or excessively disturbing than the norm. The key feature of this disorder is the fact that even at a low intensity level, these stimuli can trigger reactions and the symptoms associated with the condition such as headaches, concentration difficulties and tiredness (Paulin, Andersson, & Nordin, 2016; Baguley, 2003).

Due to past literature using the terms hyperacusis, phonophobia and dysacusis relatively interchangeably when addressing the auditory perceptual phenomenon, Phillips and Carr (1998) suggest that this interchangeability in terminology could entail some kind of commonality to these auditory disorders. However, instead of focusing on sound sensitivity collectively, the definition of hyperacusis that has been assumed for the purpose of this study is the description as an intolerance exceeding normal expectations to commonplace environmental sounds. The same definition had been adopted from Vernon (1987) for a study on prevalence conducted by Andersson et al., (2002). It is better suited to utilise the term, hyperacusis, due to the label possessing better appropriation to define one of the focuses of the current study, general oversensitivity to sounds (Andersson et al., 2002).
Hyperacusis appears to be a fairly common disorder that may potentially affect many people and as a result have negative effects upon various aspects of modern society. Anderson et al. (2002) reported a prevalence rate of 8.6% rate in Sweden whereas a study that had collected close to the same time frame in Poland reported a prevalence rate of 15.2% (Fabijanska et al., 1999). Furthermore, hyperacusis could induce serious or debilitating issues for those who suffer from the condition. For example, sufferers may take evasive measures in many of the social, occupational and leisurely aspects of their life or depend upon devices that protect their hearing Anari et al. (1999) as cited by Andersson et al. (2002).

According to one study, common also to hyperacusis sufferers is the evidence of poor health and the diagnosis of one psychiatric condition, 47% and 8% fit the description for anxiety and depression, respectively (Jüris et al., 2013). Many of these issues prompted the motivation for the research in the present study, which has had fairly little research conducted on the subject, so far. Hyperacusis also has a tendency to be common for other conditions such as tinnitus, which unlike hyperacusis is a medically explained symptom. This in turn could add to the explanation underlying the under-reported prevalence of hyperacusis in the general population given by Marriage and Barnes (1995), as cited by Andersson et al., (2002).

The present study is based on a model of a previous experiment conducted by Andersson et al., (2013) that studied the perception, symptoms and responses observed in participants during their exposure to odorant chemicals in a chamber. The study found that those who displayed chemical sensitivity disorders differed in their responses and perception to chemical exposure. In order to investigate the possibilities that sound exposure could have on those with auditory disorders such as hyperacusis, measures were taken to observe the effect that a disturbing noise source had on sound sensitive individuals. I should expect that in the same sense that those suffering from a disorder in loudness perception like hyperacusis should show no habituation to disturbing sound stimuli unlike non-sensitive participants.

Based on the information that has been presented above, it was hypothesised that persons who are relatively high on sound sensitivity would compared to those low on sound sensitivity perceive sound exposure as more intense, unpleasant and negatively affecting their concentration, and would also report more symptoms. Additionally, my second hypothesis is that those who are relatively high on sound sensitivity should show poorer cognitive performance on a cognitive performance tasks, as compared with a low sensitivity group of individuals, as a result of the rise in attentional decrease and the difficulties in holding concentration during sound exposure.
Method

Participants

A sample of 40 participants from the Umeå region had been recruited into the present study through the combinatorial employment of local newspaper ads, online ads and billboard advertising within the Umeå University campus area. The ads aimed at finding participants who self-reported sensitivities to sound or, on the contrast, claiming to be particularly non-sensitive to extraneous noise. First, the participants were asked to submit in an online questionnaire that included a question about whether they considered themselves to be more sensitive to sounds than the norm, more non-sensitive to sounds than typical or whether they considered themselves as relatively normal in their perception of sounds. According to their responses, in this case, if participants had informed of an attribution to either being more sound sensitive or non sensitive, they were then selected into the study. In total, the sample consisted of 18 male participants and 22 female participants who were then divided into two groups. No participants were excluded from the study.

A post experiment questionnaire that was later distributed online by e-mail to all participants would consist of a 21-item Noise Sensitivity Scale (NSS) developed by Weinstein (1978). The NSS questions were used to numerically value individual reactions to environmental sounds. Based on their responses to the NSS, they were grouped accordingly to either a High NSS group or a Low NSS group based on median split. See Appendix for the 21-item NSS. Previous studies demonstrated that the NSS scale had good test, re-test reliability, exhibited validity in field, laboratory studies, additionally including internal consistency (Nordin et al., 2013).

Both the low NSS and high NSS group had 20 participants. The mean scores and standard deviations for low NSS group and high NSS groups were 41.25 and 8.025 and 64.2 and 8.942, respectively. The low NSS group had 12 men and 8 women whereas the high NSS group had 6 men and 14 women. The youngest participants in our sample were 18 years old and the oldest participant was 54 years old. The mean age and standard deviation of the participants for the low NSS group was 24.15 and 5.008 whereas the high NSS group had a mean age of 30.00 and the standard deviation for that group being 10.652, respectively.

All participants were given information both in written and verbal form. Ethical approval was given by the Umeå Regional Ethics Board (Dnr 2016/51-31). All participants gave their informed consent to participate in the study. No exclusionary factors were used apart from being able to understand Swedish to a satisfactory standard. Participants did not have to claim a medical or physician’s diagnosis of a sensitivity to sound for the participation of this study. Compensation for participation in the study was 200 SEK.
Materials and procedure

Sound exposure and chamber

Prior to the study being made, a seated sound proof cubicle had been sourced that could house a participant for an exposure period of 45 minutes. A microphone and speaker had been internally fitted into the cubicle. E-prime would be running through a monitor placed outside the booth, and a keypad was handed prior to exposure enabling participants to engage with the tasks that had been requested to be followed.

The choice of sound for exposure was white noise. White noise was selected for the reason that it was a sound signal containing all frequencies being played at random, but at a constant spectral density. Also filling the criteria for the choice of sound was it being a potentially unpleasant auditory exposure source. The sound or track itself consisted of eleven minutes silence, after which the sound stimulus began to increase for nine minutes. Past 20 minutes into the exposure session, the sound played at a maintained peak had a sound pressure level (SPL) of 60 dB. This SPL of white noise carried on for a remaining 25 minutes in the exposure session (See Figure 1).

Figure 1. Overview of tasks over the exposure session.

Tasks

Perceptual ratings

Over the course of the experimental exposure session, participants were required to rate the perceived intensity, unpleasantness and effect the exposure of the sound had on their concentration using a Borg CR-100 scale (Borg & Borg, 2002). This scale is a verbally anchored ratio scale. The numbers on the scale are described as follows: 0 Nothing, 2 Minimal, 3 extremely weak, 6 very weak, 13 weak, 25 moderate, 38 strong, 50 very strong, 70 extremely strong, 100 maximum and theoretically higher levels around 120. The descriptions would correspond to the relevant numbers that had been outlined, so that participants would be able to subjectively report according to how the exposure was affecting them at various intervals. These were also asked to be rated at 14 separate occasions that included a preliminary, pre-exposure point (see Figure 1).
Symptom ratings

Using the same Borg CR-100 scale, nine symptoms were also rated. These were as follows; eye irritation, nervousness, heaviness in the chest or breathing difficulties, concentration difficulties, dizziness, tiredness, headache, nausiness, irritation (emotional). These were chosen in adherence to a previous study that was conducted by Andersson et al. (2013) and in reference to the data from Andersson et al. (2002) study who found that these were a series of some of the symptoms hyperacusis complained of suffering from. The choice of these particular symptoms also represent a wide range of symptoms that have some potential to be brought on by those who may suffer from sound sensitivity. These were also asked to be rated at 4 occasions including a preliminary, pre-exposure point (see Figure 1).

Cognitive performance task

To measure the participants’ cognitive performance during the exposure session, they were given an N-back task. The N-back in this study was a 3-back (Dobbs & Rule, 1989), in which they had to correctly remember whether the number that was displayed on the screen was the same as the number that had appeared 3 steps before. Participants had to click either a yes or no key on the keypad according to the response they believed was true for each number of the task. The 3-back tasks were administered first at baseline and lastly at the end of the exposure session during the maintained peak noise exposure period (see Figure 1).

Design and Procedure

An overview has been provided above of the experimental procedure in Figure 1. Prior to the exposure session, after participants had been placed in the soundproof booth, the participant were asked to fill out the preliminary sections rating intensity, unpleasantness, concentration and symptoms according to the Borg CR-100 scale, after which the experiment and the sound file were initiated through E-prime. Participants had to follow the corresponding instructions on the screen in order to follow through each section of ratings and undertake the cognitive performance tasks as the 3-back in this case. Guided through the program they had to fill out the same questionnaire over the course of the experiment that asked participants to rate the perceived intensity, unpleasantness and effect on concentration. Over the course of the experiment participants were subjected to white noise inside the booth that would increase in SPL as the duration of the experiment progressed. Following after the experimental exposure session the participants were administered an online post-experiment survey.
**Statistical Analyses**

IBM SPSS Statistics was used to generate analyses through independent sample t-tests for ratings of intensity, unpleasantness, effect on concentration, symptoms as well on individuals cognitive performance on the n-back task. All ratings for the 9 symptoms were taken collectively and an average was made, in order for the use of t-test analyses. An additional two-way mixed model analysis of variance (ANOVA) with time as a within group factor and NSS group as a betweens group factor was employed for n-back performance, to a possible interaction effect. The α was set to 0.05.

**Results**

Results from the t-tests are shown in Table 1.

*Table 1. Results from t-tests separately for significant and non-significant differences.*

<table>
<thead>
<tr>
<th></th>
<th>Significant</th>
<th></th>
<th>Non-significant</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>t-value</td>
<td>p-value</td>
<td>Eta-square</td>
<td>t-value</td>
</tr>
<tr>
<td>Intensity</td>
<td>&lt;1.57</td>
<td>&gt;0.127</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Unpleasantness</td>
<td>&gt;2.48</td>
<td>&lt;.020</td>
<td>&gt;.78</td>
<td>&lt;1.71</td>
</tr>
<tr>
<td>Concentration</td>
<td>&gt;2.63</td>
<td>&lt;.014</td>
<td>&gt;.83</td>
<td>&lt;.632</td>
</tr>
<tr>
<td>Symptoms</td>
<td>&gt;2.41</td>
<td>&lt;.022</td>
<td>&gt;.76</td>
<td>&lt;.785</td>
</tr>
<tr>
<td>Cognitive performance</td>
<td>&lt;.793</td>
<td>&gt;.433</td>
<td></td>
<td></td>
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</tbody>
</table>
Intensity, unpleasantness and concentration ratings

Mean ratings of intensity, unpleasantness and effect on concentration are shown in Figure 2.

*Figure 2.* Mean ratings and standard error of the mean of intensity, unpleasantness and concentration for the two sensitivity groups.
For each of the 14 data points comparing the two groups, t-tests were conducted for intensity, unpleasant and concentration ratings. For all 14 points in time, there were no significant differences between the high NSS group and the low NSS group for the ratings of intensity. However, significant differences between the high NSS and low NSS groups can be seen in the analyses after and onwards from the first increase time point of SPL on ratings of unpleasantness and the effect on concentration.

**Symptom ratings**

Mean ratings of symptoms are shown in Figure 3.

*Figure 3. Mean and standard error of the mean of symptoms ratings for the two sensitivity groups.*

No significant differences were observed at the first two baseline ratings. After the second time point, baseline 2, significant differences appeared between the two groups.
Cognitive performance scores - n-back tasks

Mean and standard error of the mean ratings for 3-back task shown in Figure 4 below.

Figure 4. Mean and standard error of the mean for n-back performance both at baseline and at peak for the two sensitivity groups.

The high NSS group reported a slightly higher mean but not statistically significant score for the first N back task at baseline and a slightly lower mean score at exposure compared to the low NSS group. However, a further analysis, motivated by the apparent interaction and hypothesis was conducted using a two way mixed model analysis of variance with time as a within group factor and NSS group as a betweens group factor to study the interaction effect that can be observed in Figure 4 above. The analysis showed a significant interaction effect (F=2.38; p<0.031).
Discussion

The present study aimed to investigate the affective and behavioural reactions that would be found in response to annoying sound source exposure. Part of the interest would be in the subsequent effects that were made on self reports of cognitive difficulties and irritation (annoyance, distress) from individuals displaying high levels of sound sensitivity in comparison to persons with low levels of sound sensitivity.

To recap, the first hypothesis of this study stated that the high NSS group would rate more highly with regards to perceived intensity and unpleasantness and rate more negatively towards the sound stimulus’s effect on their concentration. The analyses of unpleasantness and concentration confirm the first hypothesis in part by revealing that the high NSS group had made significantly higher ratings of the exposure to the sound than the low sensitivity group. Ratings of intensity, however, did not significantly differ between the two groups, counter to what was expected by the first hypothesis. Ratings of symptoms also confirmed the first hypothesis as ratings of symptom perception increased as the sound stimulus came in. As stated by Palmquist et al. (2014), citing Sorg (1999); intolerant persons respond to levels of exposure that are typically non harmful, substantially lower than would be considered to be harmless levels which do not cause any reactions amongst people with normal perception, so to an extent this is also to be expected.

The second hypothesis stated that as a result of the exposure the high NSS group would be unable to perform as well on the cognitive task, 3-back, as the low NSS group. Although my analyses show that there were no significant differences between the two groups with regards to their performance on the task prior to exposure, at baseline level and then towards the end of the exposure period, at the maintained peak; an interaction effect was identified. Despite the finding of improvement in performance in both groups on the second session of the 3-back task, a further analysis of this interaction effect showed that the high NSS group were not able to improve as much as the low NSS group in the second 3-back task. It could be apparent to suggest that although both groups were able to improve for the secondary 3-back task, the High NSS group were in fact unable to improve due to the effect the noise had on their ability to concentrate, as denoted by the high NSS group’s significantly higher negative ratings over the course of the exposure session. This observation also partly validates the expectations of the second hypothesis of this study.

The differences in the age and gender of the two groups are unsurprising. In the high NSS group, two characteristics are clear, more women are present as well as the mean age of the group being higher than the low NSS group. This can be corroborated by the findings of the previous study on a Swedish populace, in which it was more common for women to report having hyperacusis (Andersson et al., 2002). Although opposite gender differences were found in the study conducted in Poland, in which hyperacusis was more common in men (Fabijanska, 1999). Similarly, with regards to comments about age; increased age has been thus far associated with the prevalence of hyperacusis (Andersson et al., 2002).

Perhaps an explanation for the findings of this study partly can be referred to a comment cited by Andersson et al. (2002) when a co-existence of psychological problems and noise sensitivity had been found in Stansfeld (1992) community survey. This was partly argued further when Weinstein (1980) suggested that sensitivity to noise could be a characteristic to
personality, thus partially explaining a potential cause in the higher ratings observed by sound exposure in the study. The increase in ratings of unpleasantness and negative effect, the exposure of the sound had on their concentration can also be linked to anxiety felt by those in the more highly sensitive to noise. Palmquist et al. (2014) mentions that environmental intolerances such as the case of hyperacusis are associated with an increase in stress, attention to exposure as well as an increased awareness of health concerns. This was demonstrated in the study, when symptoms were reported as the exposure session continued as well as increases in ratings of unpleasantness and intensity.

There is the potential issue of Type I errors occurring during the analysis of the 14 data points that had been acquired for ratings of intensity, unpleasantness and effect on concentration. One of the measures that could have been taken, was to adopt a stricter $\alpha$ level than the 0.05 and drop it to 0.01 to limit the risk of any significant difference being accountable to chance. However, group differences with regards to ratings of perceived unpleasantness and effect on concentration are so consistent during exposure that it is very unlikely that any Type I errors had emerged in the data of this study.

Despite non-present training trials of n-back tasks for participants prior to the experimentation I still have valid results. However, the presence of a training trial test may have potentially minimised the outcome being skewed from the possibility of a learning effect on the results of this study. Furthermore, a comment should be made to the use of only one cognitive test used to test baseline performance and final performance, additional cognitive performance assessing tasks such as a Stroop test may have been been ideal to improve the validity of our findings about the effect on concentration.

In this study, we used the 21 item NSS to categorise the participants into the two groups; low NSS and high NSS. The 21 item NSS was developed by Weinstein (1978). The questionnaire was made to generate responses to affective, behavioural reactions to noise, without relating noise as an environmental problem. Studies on the NSS scale found that it showed good test, re-test reliability, internal consistency and demonstrated validity in both field, laboratory studies (Nordin et al., 2013).

The focus of the study was primarily aimed at adults as a vast proportion of studies on sound sensitivity has concentrated its focus of research on hyperacusis found in adults. Although this continued focus makes sense, considering how the prevalence of hyperacusis appears to increase with age. It is also common, however, for a reduction in a person’s ability to hear as one continues to age. So it would be of interest in the future, to concentrate some further research on a younger demographic of the population. Notably, a study by Olson and Erlandsson (2003) reported a prevalence rate of 17.1% among adolescents between the ages of 13 and 19. In cases reporting prevalence rates such as this, it would be of much interest to see whether further studies in sound sensitivity on young people would be able to shed light on the development aspects and risk factors involved in hyperacusis onset.

This study followed on from the fact that two studies from Poland and Sweden, imply hyperacusis is a condition is not as rare a condition to the population as could be suspected. As such, this study found that those displaying hyperacusis are able to be affected by noise or sound in a negative manner, suggesting that the findings of the study may be of valuable interest to many organisations in charge of personnel, such as human resources departments
in occupational settings or environmental public health agencies in their respective
governments. Physiological readings would also be a highly recommendation area of
exploitation for further testing in the future. Independent of the data that would be given from
individual's written ratings of their perception to noise exposure, physiological readings
would be able to give cues about unconscious states and reactions that participants are
experiencing to this exposure. Such complementary studies would be of great significance as
hyperacusis is continued to be studied and attempted to made greater understanding of.
References


Appendix. The 21-item Noise Sensitivity Scale.

1. I wouldn't mind living on a noisy street if the apartment I had was nice.
2. I am more aware of noise than I used to be.
3. No one should mind much if someone turns up his stereo full blast once in awhile.
4. At movies, whispering and crinkling candy wrappers disturb me.
5. I am easily awakened by noise.
6. If it's noisy where I'm studying, I try to close the door or window or move someplace else.
7. I get annoyed when my neighbors are noisy.
8. I get used to most noises without much difficulty.
9. How much would it matter to you if an apartment you were interested in renting was located across from a fire station?
10. Sometimes noises get on my nerves and get me irritated.
11. Even music I normally like will bother me if I'm trying to concentrate.
12. It wouldn't bother me to hear the sounds of everyday living from neighbors (footsteps, running water, etc).
13. When I want to be alone, it disturbs me to hear outside noises.
14. I'm good at concentrating no matter what is going on around me.
15. In a library, I don't mind if people carry on a conversation if they do it quietly.
16. There are often times when I want complete silence.
17. Motorcycles ought to be required to have bigger mufflers.
18. I find it hard to relax in a place that's noisy.
19. I get mad at people who make noise that keeps me from falling asleep or getting work done.
20. I wouldn't mind living in an apartment with thin walls.
21. I am sensitive to noise.

The NSS is answered to as follows; agree strongly (0), agree (1), agree mildly (2), disagree mildly (3), disagree (4), disagree strongly (5).