**Results**

**Speech Perception in Noise**

The speech in noise scores were retained in their percentage form to preserve the nature of the actual distribution (Fig. 3). Arcsine transformation which is typically used on this type of data was not used since data did not violate equality of variances (Levene’s test) nor did it significantly deviate from normal distribution based on Shapiro Wilk’s test of normality. The control group performed better (Mean=73.67%, SD=3.6%) than the noise exposed group (Mean = 69.67%, SD = 3.98%), and it was statistically significant based on Two Independent Samples t test (t(1,22) = 2.58, p = 0.017, d = 1.054).

**Fig. 3** Half violin plot of Speech in noise performance in the control group and noise exposed group. Mean and 95% confidence intervals are indicated. The control group tended to perform better with a greater number of individuals scoring higher. However, quite a bit of overlap between the groups was seen.

**Gap detection**

Gap detection thresholds were smaller in the control group (median = 2.08 ms) than the noise exposed group (median = 3.3 ms). Since the detection thresholds in the control group had a large right skew, a non-parametric inferential test and a corresponding effect size calculation procedure was employed. Mann Whitney U test was used for comparison between the groups, and it was statistically significant (U = 18.0, p = 0.002, r = 0.64). Some individuals in the noise exposure group did perform equivalent to those in the control group while some in the control group had scores similar to those in the noise exposed group. (Fig. 4).



**Fig. 4** Box plot of Gap detection thresholds (ms) in control and noise exposed groups. Asterisk indicates the mean in each group. The noise exposed group had higher gap detection thresholds than the control group. Two subjects in the control group had scores greater than the mean of the noise exposed group while two in the noise exposed group had thresholds near the control mean.

**Amplitude Modulation detection**

Modulation detection thresholds became poorer with increase in modulation rate. Modulation detection thresholds (Table 1 & Fig. 5), on an average were better in the control group than the noise exposed group, but Multivariate analysis of ANOVA with Bonferroni adjustment revealed no statistically significant main effect of group on the conditions as a whole (F(4,19) = 1.18, p = 0.351, ƞp2 = 0.199).



**Fig. 5** Box plot of Temporal modulation detection thresholds in the control and noise exposed groups at different modulation rates. Colored asterisks indicate the respective mean values. Significant overlap of values can be observed though the noised exposed group tended to have poorer thresholds.

**Table 1** Mean and Standard deviations of the modulation detection thresholds in the control and noise exposed groups across modulation rates

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  | 8 Hz | 30 Hz | 60 Hz | 200 Hz |
| Control | -15.80 (1.82) | -14.39 (2.69) | -12.5 (2.43) | -9.30 (2.07) |
| NoiseExposed | -14.95(1.96) | -12.62 (1.79) | -10.68 (2.06) | -7.74 (1.78) |

**Discussion**

**Speech in Noise perception**

Speech perception in noise performance was significantly poorer in the noise exposed group than the control group. This is in agreement with results from Hope et al, 2013 who reported that speech in noise performance on VCV syllables was nearly 4 dB worse in the Royal air force aircrew compared to the administrators though TEOAE amplitudes were not significantly different between the groups. Similarly, Liberman et al., 2016 reported poorer performances with NU-6 word recognition in noise as well as with speech distorted with time compression and reverberation in their high-risk group. However, Grose et al., 2017 reported no significant differences in BKB sentence perception in noise between those with and without frequent musical concert attendance in their sample of young adults.

Several other studies have investigated speech perception in noise performance in subjects exposed to noise, but nevertheless had hearing sensitivity within normal limits. However, the status of otoacoustic emissions went unreported in these studies. Kujala et al., 2004 for example, reported affected phoneme discrimination based on a behavioral task as well as Mismatch negativity response. Brattico et al., 2005 used vowels and reported greater activity in the Right hemispheres than the Left in the noise exposed group while it was the opposite lateralization in the control group. Kumar et al., 2012 reported poorer speech recognition abilities in multi talker babble in train drivers compared to their age matched controls. Soalheiro et al., 2012 found that as many as 82% of workers exposed to occupational noise complained of speech perception difficulties while still having thresholds within 25 dB HL. Similarly, Spankovich et al., 2018 reported self-reported deficits in speech in noise perception to be associated with noise exposure.

Recent studies have led to an understanding that the Inner hair cell ribbon synapses (Wan & Corfas, 2015) with the auditory nerve are the most vulnerable structures to any kind of damage rather than the hair cells or the neurons themselves (Sergeyenko et al., 2013, Bourien et al., 2014, Kujawa & Liberman, 2015; Liberman et al., 2016). More specifically, cochlear synaptopathy has been linked with the loss low spontaneous rate neuron synapses (Liberman & Liberman, 2015) which are associated with high intensities and signal in noise encoding (Liberman, 1978, Young & Barta, 1986). Noise induced cochlear synaptopathy may thus explain some of these deficits in speech perception in noise. In effect, noise exposure may lead to a form of a ‘hidden hearing loss’ (Schaette & McAlpine, 2011) that does not show up on conventional audiometry (high spontaneous rate neurons responsible for threshold levels are not as affected by noise exposure), but likely affects aspects of suprathreshold aspects of audition (Furman et al.,2013).

Many other studies have used a correlational research design to investigate the relationship between speech perception in noise and some form of noise exposure rating (effectively making the latter, a continuous variable). It is to be noted these were typical subjects and not those exposed to regular occupational noise. Correlations were largely absent between speech perception in noise and noise exposure in most of the studies (Prendergast et al., 2017, Yeend et al., 2017, Fullbright et al., 2017, Grinn, 2017, Guest et al., 2018, Le Prell et al., 2018, Bramhall et al., 2018, Valderrama et al., 2018). However, Liberman et al., 2016 reported that better speech in noise performance was associated lesser noise exposure. The task was designed to be difficult with poor SNR, time compression and added reverberation. Similarly, signal detection in noise was found to be poorer in rats exposed to noise in difficult SNRs only (Lobarinas et al., 2017). It is possible that the task difficulty matters for the detection of subtle effects on speech perception caused by acute, variable and irregular noise exposure in the general population. In those exposed to regular occupational noise exposure though, the effects maybe more prominent. Variability in reported findings, we will see, extends to temporal processing domain too.

**Gap detection and Amplitude modulation detection**

Gap detection thresholds were poorer in the noise exposed group than the control group indicating that some aspect gross temporal processing could be affected by noise exposure. Modulation detection threshold difference between the groups was not statistically significant. However, there was a trend of better modulation thresholds on an average in the control group across modulation rates, especially at higher modulation rates. Kumar et al., 2012 found no difference between the control and noise exposed groups in gap detection performance, but found significantly poorer modulation detection thresholds at higher modulation rate along with affected duration pattern scores in the noise exposed group. Paul, Waheed, Bruce and Roberts, 2017 also reported that amplitude modulation detection thresholds with a 5000Hz tone carrier were on an average, poorer in the high noise exposure group.

Kumar et al., 2013 hypothesized that synaptopathy may lead to poorer phase locking and reduced synchrony in auditory nerve firing. Loss of ribbon low spontaneous rate neuron synapses critical for phase locking (Bharadwaj et al., 2014; Kobel et al., 2017) may have a deleterious effect on temporal fidelity of neural encoding. Noise-induced demyelination may be another disrupting factor in the mix (Skoe & Tufts, 2018). Reduced phase locking and lower EFR amplitudes have been reported in mice exposed to neuropathic noise (Shaheen et al., 2015). Skoe and Tufts, 2018 not only reported delayed ABR latencies for waves I, III and V, they also showed delayed I-V interpeak (as did Valderrama et al, 2018) latencies at higher repetition rates in the higher noise exposure group. So, there is a basis for possible temporal processing deficit in those exposed to noise. Indeed, studies have shown that synaptopathy may be one of the factors contributing to individual variations in temporal processing (Bharadwaj et al., 2015, Mehraei et al., 2017).

However, when studies have adopted a correlational approach to investigate the relationship between noise exposure (as a continuous variable) and temporal processing, the association has been largely negative (Yeend et al., 2017; Prendergast et al., 2017; Guest et al., 2017). Prendergast et al., 2017 for example, collected behavioral data on a wide array of tasks (from frequency and intensity difference limens to Musical consonance detection task) on a large sample (n = 138) of ‘normal’ hearing young adults with varying self-reported exposure to noise and reported that they found no correlation between any of these tasks and magnitude of lifetime exposure to noise.

**Equivocal findings in studies**

The differences in findings reported in literature are likely to arise due to heterogeneity in a number of factors. The type of noise, its spectrum and intensity as well as duration of exposure could be quite different among the subjects. For example, many studies considered participants from the general population with varying exposure to noise (Prendergast et al., 2017, Yeend et al., 2017, Bramhall et al., 2017, Grinn et al., 2017) while others specifically considered participants with a regular exposure to occupational noise and compared them to a control group (Hope et al., 2013, Kumar et al., 2013). Individual variability in susceptibility to noise could be another factor (Henderson, Subramaniam & Boettcher, 1993). The method used to measure exposure to noise and the protocol used (Valderrama et al., 2018) could have contributed to differences in findings too. Thresholds at very high frequencies could be a factor too since studies have reported poorer thresholds at extended high frequencies in noise exposed subjects (Liberman et al., 2016). High pass masking noise could be used in future studies to control for this in future studies (Hickox et al., 2017).

Nevertheless, considering the equivocal findings including that of the present study, it would seem that the link between possible synaptopathy and psychoacoustic test results is rather tenuous, and it may just be one of the many factors affecting suprathreshold perception. Other aspects like attention, working memory, and efferent activation (Yeend, Beach, Sharma & Dillon, 2017) maybe relevant and important. It is also possible that effects of cochlear synaptopathy become more measurable with more extreme exposure to noise and may occur along with some form of hearing loss (Prendergast et al., 2017). Finally, synaptopathy is also linked with various factors like age (Sergeyenko et al., 2013; Mohrle et al., 2016), ototoxicity (Bourien et al., 2014; Li et al., 2016) and auditory symptoms like tinnitus and hyperacusis (Schaette & McAlpine, 2011; Knipper et al., 2013; Hickox & Liberman 2014; Schaette et al., 2014; Guest et al., 2017) which can all interact in a complex fashion to produce a whole spectrum of results.

**Summary and Conclusions**

We found that poorer Speech in noise performance and larger gap detection thresholds in the noise exposed group. Amplitude modulation detection thresholds also tended to be worse, particularly at higher modulation frequencies. Poorer suprathreshold perception with clinically normal hearing sensitivity and unaffected distortion product oto-acoustic emissions suggest a hidden hearing loss due to occupational noise exposure. We recommend greater sensitization towards the use of ear protective devices in those chronically exposed to noise (even if noise is below levels expected to cause permanent threshold shift). There is also an argument to be made for a regular screening for suprathreshold auditory deficits in the at-risk population. That said, the effect of noise exposure on human auditory system may not be systematic and predictable and is bound to get affected by a host of other factors including genes and lifestyle. So, heterogeneity in our sample and the variability in findings reported are to be expected. The subtle nature of the disorder requires that the studies employ larger samples and actively attempt to replicate previous findings so that genuine remain as a common factor, which can then be used to tailor a diagnostic protocol to evaluate these subtle deficits better.