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Wind farm infrasound detectability and its effects on the perception of wind farm noise amplitude modulation

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ABSTRACT

Some residents attribute adverse effects to the presence of wind farm (WF) infrasound. However, dominant features of windfarm noise such as infrasound, tonality and amplitude modulation span the average human hearing threshold, so attribution to infrasound is problematic. This study used a combination of pre-recorded noise stimuli, measured at 3.2 km from a wind farm, in laboratory-based listening tests to investigate human perception of infrasound and amplitude modulation at realistic sound pressure levels in a group of 14 participants. Although a small sample size warrants cautious interpretation, preliminary results suggest differential effects between self-reported non-sensitive versus noise-sensitive participants, where the latter detected infrasound above chance. Infrasound did not affect the perception of amplitude modulation. Larger studies remain needed to clarify these findings.

1 INTRODUCTION

Wind farm (WF) infrasound remains controversial and the source of substantial debate regarding potential effects of wind farm noise (WFN) on human health. The main infrasonic components of WFN can be measured many kilometres away from a wind farm, but typically at levels deemed well below the normal hearing threshold (Zajamšek et al. 2016, Turnbull, Turner, and Walsh 2012, Jakobsen 2005). The evidence for infrasound-specific effects on human health is very poor. A key hypothesis that has been advanced to explain wind farm noise related complaints, and partly supported by animal studies, suggesting that WF infrasound could potentially be detected by the ear, yet not heard, although supporting evidence from human studies remain lacking (Salt and Hullar 2010). Some symptoms reported by humans in relation to wind farm noise exposure, such as headache, ear pressure, dizziness and nausea, appear to be independent of the presence or absence of synthesised infrasonic tones with somewhat unrealistic characteristics and noise levels (Crichton et al. 2014). Using more realistic levels of infrasound Tonin, Brett, and Colagiuri (2016) also found no effects, although it remains unclear if synthesised infrasound is sufficiently representative of real wind farm noise to rule out infrasound effects. A further limitation is that short-term infrasound exposures used in both studies (Tonin, Brett, and Colagiuri 2016, Crichton et al. 2014) may have been too short to elicit symptoms. On the other hand, a response to a 200-second infrasonic tone at 12 Hz was measured in humans using magnetic resonance imaging (MRI), which showed an increase in brain activity evoked by infrasonic tone exposure (Weichenberger et al. 2017). While this supports that infrasound exposure can elicit a brain response, these results cannot be extrapolated to WF infrasound due to the use of unrealistic character of stimuli at an unrealistically high sound pressure level. Therefore, further evidence is needed to establish whether WF infrasound at ecologically meaningful levels can be perceived by humans.

Recently it was shown that a low-frequency tone modulated at an infrasonic rate is perceptually similar to a stimulus containing both a low frequency tone and an infrasonic tone (previously termed “infrasonic modulator”) (Marquardt and Jurado 2018). In the latter case, the presence of the infrasonic tone causes the low-frequency tone to be perceived as though it were amplitude modulated. The infrasonic tone in these experiments was audible

(50 phon) and the authors questioned whether much quieter WF infrasound could potentially be perceived via amplitude modulation.

The aims of this study were twofold: 1) To investigate whether humans can perceive measured WF infrasound at realistic levels, and 2) To determine if the presence of infrasound effects the perception of wind farm noise amplitude modulation (AM). We build upon the work of Crichton et al. (2014) and Tonin, Brett, and Colagiuri (2016) by using a short term listening test (within 30 minutes) to study the perception of WF infrasound. However, in this work we used real WFN at a realistic sound pressure level of 48 dB(G). We also build upon the work of (Marquardt and Jurado 2018) by investigating whether a low-frequency tone in the presence of infrasound alters the perception of a low-frequency tone that is already amplitude modulated. All stimuli used were real WFN to maximise the ecological validity of the experiment.

2 MATERIALS AND METHODS

This research was been approved by the Social and Behavioral Research Ethics Committee (SBREC) at Flinders University under project number 7536.

2.1 Participants

Fourteen participants (6 males) aged 21 to 80 years old took part in the experiment. Eleven participants were students and researchers at the Adelaide Institute for Sleep Health (AISH), and 3 participants were residents living near wind farms in South Australia.

2.2 Stimuli design

WFN was measured at a residence located 3.2 km from the nearest wind turbine from a South Australian wind farm. Twenty 10-minute samples with amplitude modulation depth between 3 and 12 dB and a tonal audibility between 5 and 10 dB were randomly selected. The AM depth and tonal audibility were quantified using modified IOA and IEC methods, respectively, as described by Hansen et al. (2019). Each selected sample was listened to and visually inspected by the authors who then extracted 10-second samples ("seed" samples) with clear infrasound and AM components in the frequency spectrum. Twenty "seed" samples were then either high-pass or stop-band filtered to create 3 different types of stimuli samples #1-3 as shown in **Figure 1**. A high-pass filter (HPF) with a cut-off at 20 Hz was used to create the infrasound only stimuli and a stop-band filter (SBF) with a cut-off at frequencies between 45 and 48 was used to create samples without AM.

Samples #1-3 were arranged in three specific pairs (including Part 1: Infrasound detection, Part 2a and b: AM detection) as shown in **Figure 1**. Part 2a and 2b were used to study the effects of infrasound on the perception of tonal AM and Part 1 for detectability of infrasound. We hereafter refer to Part 1 as the infrasound detection test and Part 2a and 2b as the AM detection test.

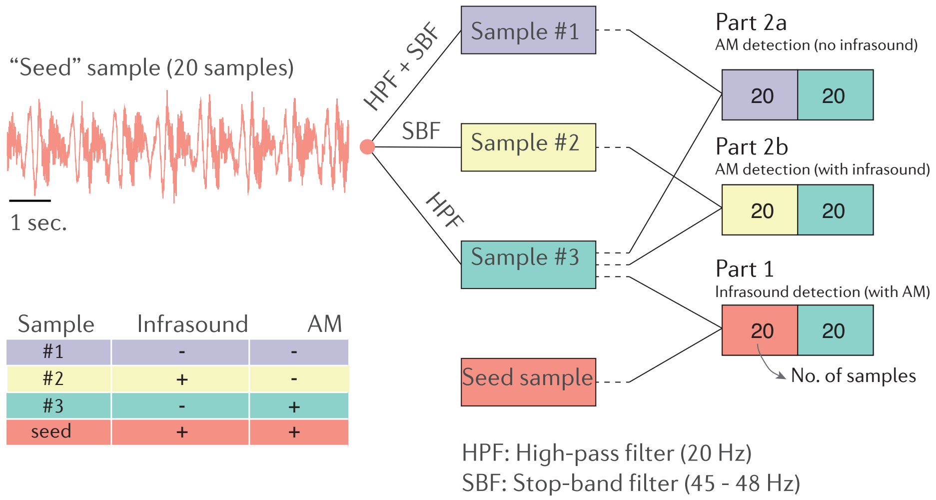

Figure 1: Stimuli design. "Seed" samples contain both infrasound and AM components; Sample #1 is without both infrasound and AM components; Sample #2 contains only infrasound component and Sample #3 contains only AM component.

2.3 Listening test design

The listening test was delivered via a MATLAB graphical user interface in three consecutive parts to cover infrasound and AM detection testing. Both were tested using the "Yes-No" approach (Macmillan and Creelman 2004) where participants were presented with a single stimulus (see Figure 1) and were then asked:

- For Part 1 (Infrasound detection tests): *Was Infrasound present?*
- For Part 2a and 2b (AM detection tests): *Was AM present?*

Response detections were used to estimate the sensitivity of each participant to correctly discriminate between stimuli containing infrasound or AM from stimuli without these features or background. In the case of the AM detection test, thus the aim was not to evaluate the detection of AM but rather to study the effects of infrasound on AM detection, which will increase or decrease detectability of AM. The investigation of infrasound detection is relatively straightforward using a sample pool with an equal number of samples with and without infrasound. However, the investigation of the influence of infrasound on AM is more complicated as it requires comparison between two detection tests. Both detection tests involved stimuli with AM while only one contained infrasound. Thus, any difference between tests can be attributed to infrasound. Ten second stimuli and each of the three Parts were presented in random order. There are 40 stimuli in each Part. Before the start of each part, participants were given unlimited opportunity to listen to samples containing AM and infrasound to familiarise themselves with the features. Participants then had two practice runs (listening to two samples and providing ratings) before listening and responding to 40 stimuli in the actual experiment. The total test time was approximately 30 minutes.

2.4 Experimental set-up reproduction

The noise reproduction system consisted of an RME BabyFace Pro sound card, modified (without vent) Krix KX-4010S commercial cinema subwoofer with 10-inch driver and Crown DC-300 power amplifier with a flat frequency response down to 0 Hz. The noise samples were calibrated using the Head Acoustics III located at the listener position at 30 ± 2 dB(A). This dB(A) level translates to 48 ± 2 dB(G) for stimuli containing infrasound. The stimuli were smoothly ramped up and down using a 0.5 second raised-cosine function. Listening tests were carried out in a bedroom at the Adelaide Institute for Sleep Health (AISH), which has a 19 dB(A) background noise level during daytime when testing was conducted. The listener sat 3 m away from the loudspeaker and was aligned with the central axis of the speaker as shown in **Figure 2a.**

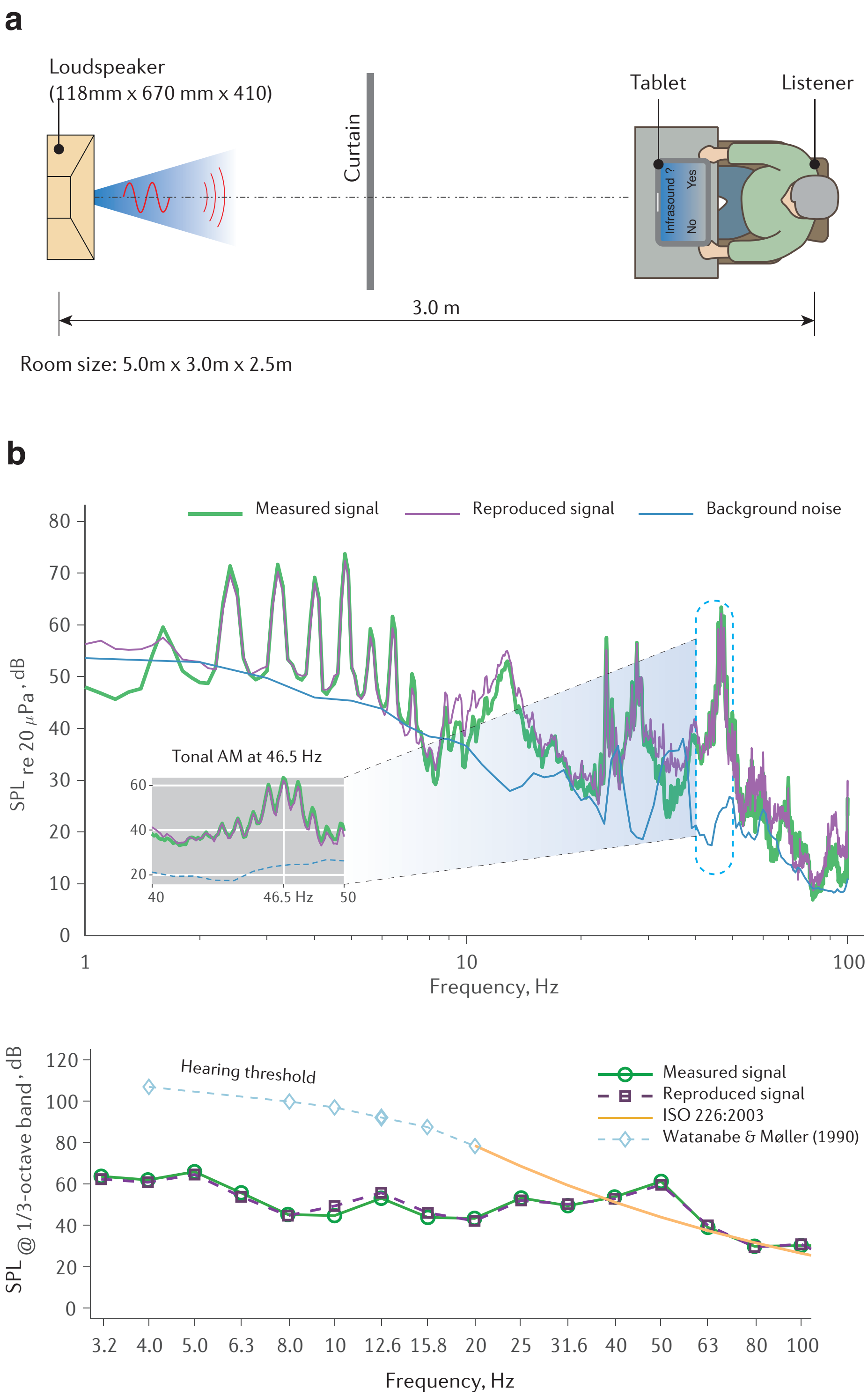

Figure 2: **a)** Experimental set-up and **b)** The indoor measured noise spectrum (in the field) and at the listener position (in the laboratory). Sample sound pressure level (SPL) in 1/3-octave bands of the samples are compared with the normal-hearing threshold curves (Watanabe and Møller 1990, ISO 2003).

There is a high agreement between the measured (in the field) and reproduced sound pressure level (SPL) spectrum, as shown in **Figure 2b**. The agreement is especially good in the infrasonic range and AM range between 40 and 50 Hz. This good agreement was achieved with equalization of the reproduced sample to compensate for loudspeaker and room responses.

2.5 Data analysis

The listening test binary results were analysed in accordance with signal detection theory (Macmillan and Creelman 2004). Each response was classified as a *Hit, Miss, Correct rejection* or *False alarm* according to correct versus missed detection of infrasound and AM, and correct rejection versus false detection in the absence of infrasound and AM respectively. This is illustrated in **Figure 3a**.

Detection theory uses a sensitivity measure, d', and bias measure c. The value of d' ranges from 0 indicating no detection (or detection by chance) to an effective ceiling of 4.65 with hit rate (HR) = 0.99 and false alarm rate (FAR) = 0.01 indicating near perfect detection. A participant can be biased towards more often saying that infrasound (or AM) is present than not and c is the measure of that bias. Both parameters are calculated based on the HR and FAR as follows: $d' = z(HR) - z(FAR)$ and $c = -\frac{1}{2}[z(HR) + z(FAR)]$, where z represents the inverse of the normal distribution function. The HR and FAR are estimated from a response matrix as shown in **Figure 3a. Figure 3b** shows a graphical representation of d' and c and the decision process behind the detection theory which assumes a normally distributed decision variable (or infrasound/AM sensation in our case). When the sensation of infrasound/AM is strong, the distributions are well separated, and the decision is easy, and the opposite is true when the sensation is weak and infrasound/AM becomes difficult to detect.

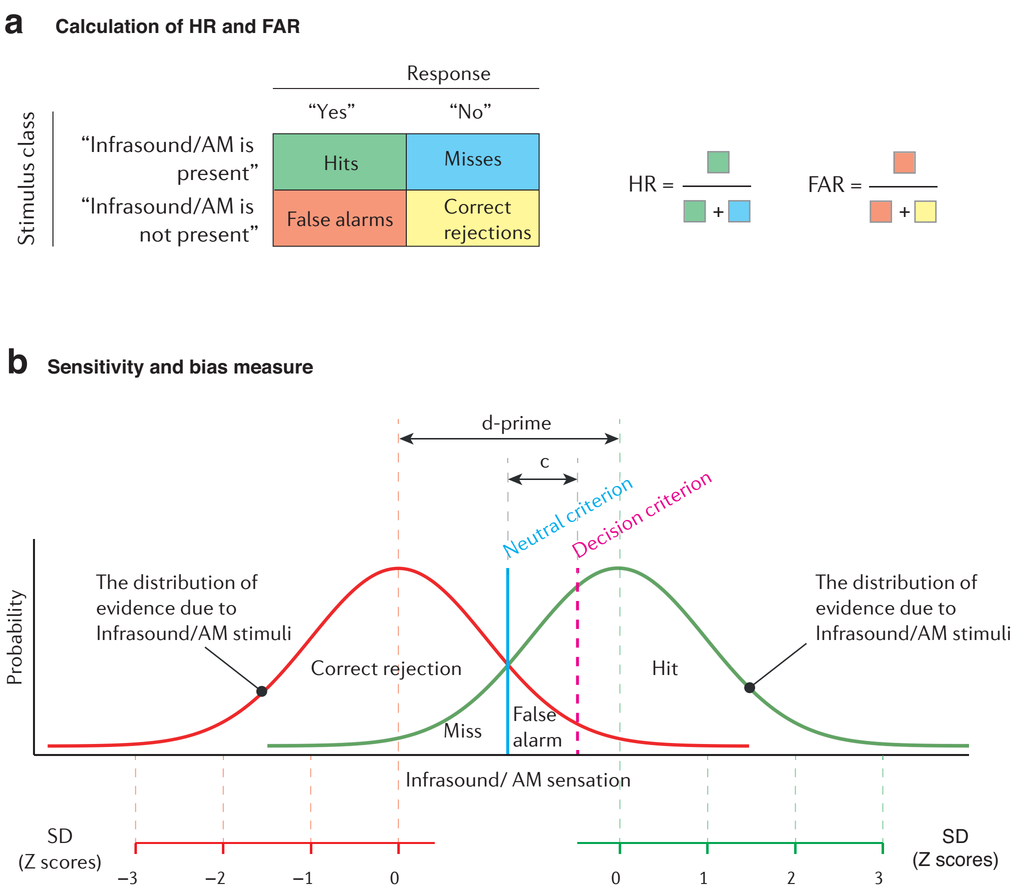

Figure 3: Graphical interpretation of detection theory showing **a)** response matrix with Hit rate (HR) and False-alarm rate (FAR) and **b)** interpretation of sensitivity, d', and bias, c, measure.

2.6 Statistical analysis

Statistical analysis (one-tailed t-test, double sided t-test, one sample t-test and paired sample t-test as appropriate) were performed using R (http://www.r-project.org/). Detection theory was performed using the package *psycho* using R (Makowski 2018). The significance threshold used in the analysis was $P = 0.05$.

3 RESULTS

3.1 Infrasound detectability

Participants were separated into 2 groups based on the Weinstein Noise Sensitivity Scale (Weinstein 1978) scores. To classify participants as either sensitive or insensitive, the sample mean was calculated. Participants with scores exceeding the mean (56 ± 17) were classified as sensitive and all other individuals were classified as insensitive. **Figure 4a** shows the individual d' for each participant, where the averaged d' is 0.051 $\pm$ 0.357 indicating that infrasound could not be detected (one-sample t-test: t_{13} = 0.536, P = 0.6) and some negative values of d' indicating HR < FAR**.** This result is perhaps of no surprise due to the low SPL of the infrasound (48 $\pm$ 2 dB(G)) which is well below the infrasound normal hearing threshold of 85 dB(G) (Leventhall, Pelmear, and Benton 2003). Although overall sensitivity was effectively 0, this changed when the group was divided into self-reported noise sensitive and insensitive sub-groups as shown in **Figure 4b**, where noise**-**sensitive participants appeared to be able to detect infrasound above chance (one-sample t-test: t_8 = 2.329, P = 0.048). The sensitivity d' was also significantly different between the noise-sensitive and -insensitive groups, as shown in **Figure 4c** (Student's unpaired two-tailed *t*-test: t_{12} = -2.706, P = 0.02). There was also a significant bias in the noise-insensitive group indicating that these participants were more likely to say that no infrasound was present (Student's unpaired one-tailed *t*-test: t_{12} = -2.037, P = 0.032, **Figure 4d**). On the other hand, noise sensitive participants were not biased, indicating that they were equally likely to respond with a "yes" or "no" to infrasound stimuli.

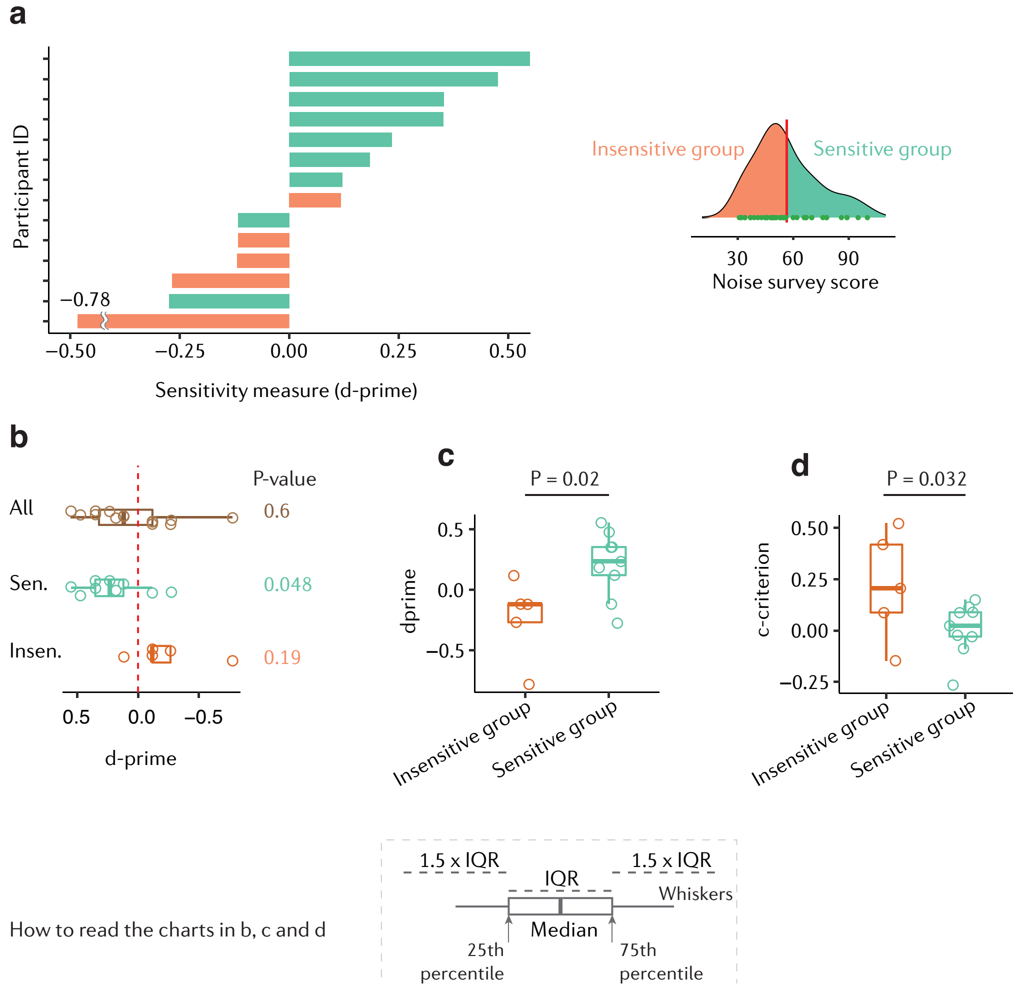

Figure 4: Infrasound detection results. **a**) sensitivity d' values and noise sensitivity distribution. **b**) Overall and group averaged d' compared against 0. d' is equal to 0 indicating performance by chance. **c**) Infrasound detection sensitivity comparison between 2 groups. **d**) Bias, c, comparison between groups. c can vary from negative to positive values. c equal to zero indicates unbiased responses. The box plots show the median (solid line) and interquartile range (IQR). Turkey-style whiskers extend to a maximum of 1.5 x IQR beyond the box.

3.2 Effect of infrasound on the perception of tonal AM

Due to a change in the selected AM stimuli to a more ecologically valid representation of wind farm AM, results of 4 participants were not incorporated in this analysis. **Figure 5a** and **b** show the detection of AM in the presence or absence of infrasound for 10 participants. Infrasound did not influence the perception either in increasing the sensitivity d' (one-sample t-test: t_9 = 0.067, P = 0.95) or the measure of bias c (one-sample t-test: t_9 = 0.325, P = 0.75).

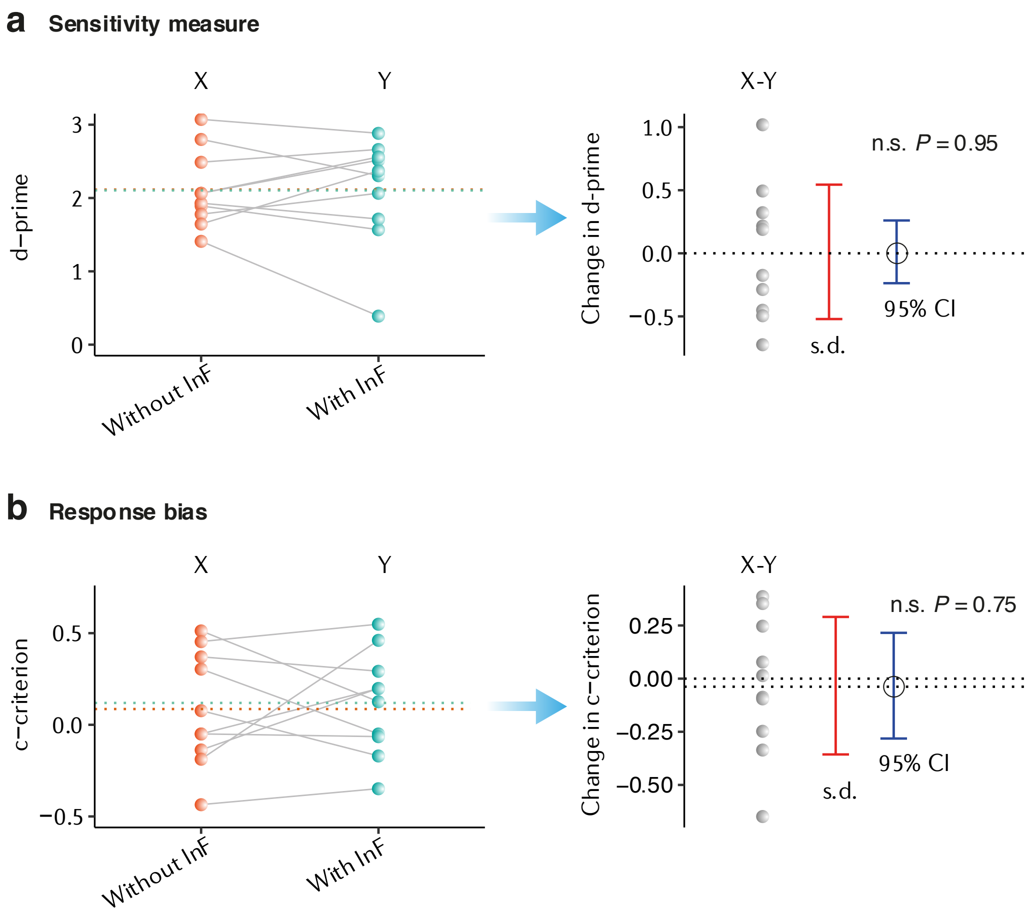

Figure 5: Pairwise comparison of stimuli with and without infrasound on AM detection. **a**) d' for two experiments and the difference between the two ($X(d') - Y(d')$). **b**) Bias measure, c, for the two experiments and the difference between the two ($X(c) - Y(c)$). Dashed lines in both sub-figures indicate mean values.

4 CONCLUSIONS

This study used a “Yes”- “No” listening test to investigate detection of infrasound and AM in the presence of infrasound for 14 participants. We found that self-reported noise sensitive individuals can detect the presence of low-level infrasound (48 ± 2 dB(G)) above chance. Furthermore, infrasound did not influence AM perception such that the detection of AM was no better or worse in the presence of infrasound. Overall these preliminary results suggest that WF noise complaints could potentially be governed to some degree by the presence of infrasound. These are pilot test results from a small sample. Consequently, further data from a larger sample size is clearly warranted to clarify the potential significance of these results.

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