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Framing sound: Using expectations to reduce environmental noise annoyance



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ABSTRACT

Background: Annoyance reactions to environmental noise, such as wind turbine sound, have public health implications given associations between annoyance and symptoms related to psychological distress. In the case of wind farms, factors contributing to noise annoyance have been theorised to include wind turbine sound characteristics, the noise sensitivity of residents, and contextual aspects, such as receiving information creating negative expectations about sound exposure.

Objective: The experimental aim was to assess whether receiving positive or negative expectations about wind farm sound would differentially influence annoyance reactions during exposure to wind farm sound, and also influence associations between perceived noise sensitivity and noise annoyance.

Method: Sixty volunteers were randomly assigned to receive either negative or positive expectations about wind farm sound. Participants in the negative expectation group viewed a presentation which incorporated internet material indicating that exposure to wind turbine sound, particularly infrasound, might present a health risk. Positive expectation participants viewed a DVD which framed wind farm sound positively and included internet information about the health benefits of infrasound exposure. Participants were then simultaneously exposed to sub-audible infrasound and audible wind farm sound during two 7 min exposure sessions, during which they assessed their experience of annoyance.

Results: Positive expectation participants were significantly less annoyed than negative expectation participants, while noise sensitivity only predicted annoyance in the negative group.

Conclusion: Findings suggest accessing negative information about sound is likely to trigger annoyance, particularly in noise sensitive people and, importantly, portraying sound positively may reduce annoyance reactions, even in noise sensitive individuals.

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1. Introduction

It has become increasingly important to understand human reactions to environmental noise given the growing pervasiveness of exposure to noise in everyday life (Stansfeld and Matheson, 2003). In particular, insight into reported noise annoyance, as a common non-auditory adverse effect of environmental sound exposure, is important from a public health perspective. This is because, although the experience of noise annoyance alone is not classified as a disease or health state, noise annoyance is related to psychological stress, which can lead to stress related symptoms and poorer subjective health (Basner et al., 2014). A relatively new source of environmental sound is that generated by wind turbines.

Harvesting wind power has the potential to provide a

significant contribution to world energy requirements, while providing health benefits associated with reduced fossil fuel emissions, such as reducing the incidence of respiratory and cardiovascular diseases linked to air pollution (Smith et al., 2013). However, although wind energy production does not generate hazardous waste by-products or release greenhouse gases which contribute to climate change, the emission of noise is linked to the experience of environmental noise annoyance in some people (Knopper et al., 2014). This is of importance because, while evidence does not indicate residents would experience direct adverse physiological effects from wind turbine sound, there are indications that wind farm noise annoyance is associated with psychological distress, perceived sleep disturbance, and subjective physical symptoms, such as headache (Bakker et al., 2012; Pedersen, 2011). Therefore, to optimise the overall health benefits associated with wind farms it is pertinent to explore the factors which influence wind farm noise annoyance, so that useful strategies can be implemented to prevent or mitigate noise annoyance in residents living in the locale of a wind farm.

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There is considerable variability in the reported prevalence of wind farm noise annoyance and the factors that explain reported noise annoyance are far from clear (Merlin et al., 2013). Annoyance with wind farm sound may be explained, in part, because mechanical sounds are more likely to be evaluated negatively than the sounds of nature, such as the sound of wind, or water, which are not generally viewed as unpleasant or intrusive (e.g. Andringa and Lanser, 2013; Yang and Kang, 2005). However, in comparison with other mechanical noises, such as industrial noise from stationary sources or transportation noise, wind farm noise annoyance has been found at relatively low noise exposure levels, suggesting that there are some variables unique to wind farm sound exposure influencing annoyance reactions (Janssen et al., 2011; Pedersen and Persson Waye, 2004).

One explanation for annoyance reactions might be that there is some idiosyncratic feature of wind farm sound that explains annoyance reactions at low sound levels. One suggestion is that exposure to the sub-audible sound or infrasound (sound below 20 Hz) generated by wind turbines accounts for elevated annoyance reactions (Pierpont, 2009). However, human beings are consistently exposed to atmospheric infrasound, created by natural phenomena such as weather variations and ocean waves, and generated by anthropogenic sources, such as traffic and air-conditioning units (Leventhall, 2006, 2013). The evidence shows that the level of infrasound measured near windfarms does not exceed levels found in everyday urban and rural environments, and that windfarm infrasound makes an insignificant contribution to the background level of environmental infrasound (Evans et al., 2013; Turnbull et al., 2012). Therefore annoyance reactions are unlikely to be explained by wind farm infrasound exposure (Bolin et al., 2011).

It has also been suggested that wind farm noise is more annoying than equivalent levels of other environmental noise because of the production of fluctuating aerodynamic sound, which embodies acoustic properties shown to contribute both to awareness of sound, and perceptions of unpleasantness (Pedersen and Persson Waye, 2008). This is supported by evidence that annoyance with wind turbine sound is associated with modulations in sound, sometimes described onomatopoeically as swishing or lapping (Pedersen and Persson Waye, 2004; Pedersen et al., 2009).

It has also been theorized that wind farm noise annoyance is related to noise sensitivity and that there is an element of inevitability that noise sensitive people will find wind turbine noise annoying, even when exposure is within recognised health and safety limits, putting them at risk of psychological stress and stress related health effects over time (Shepherd et al., 2011). While, evidence indicates noise annoyance is not closely related to a general neurophysiological sensitivity (Öhlsröm et al., 1988), consistent associations have been found between subjective noise sensitivity and noise annoyance (Job, 1988; Miedema and Vos, 2003). Subjective noise sensitivity has been found to moderate the effect of noise exposure on annoyance and has been viewed as a stable personality trait reflecting a predisposition to attend to noise and evaluate that noise negatively (Stansfield, 1992), linked to negative affectivity (Smith, 2003), and perceived stress (Nordin et al., 2013). The idea that subjective noise sensitivity may help explain reported annoyance with wind turbine sound is supported by associations between perceived noise sensitivity and annoyance found in field research (e.g. Pedersen and Persson Waye, 2008).

Wind turbine noise annoyance is also associated with a number of subjective factors, such as attitude to the visual impact of wind turbines on the landscape (e.g. Pedersen et al., 2009), attitude to wind turbines in general (e.g. Pedersen and Persson Waye, 2004), and satisfaction with the living environment e.g. (Pedersen et al., 2007). This suggests that contextual factors are also influencing annoyance reactions. One of the contextual matters likely to create

negative attitudes to wind farms, and trigger wind farm noise annoyance, is accessing material available on the internet and disseminated through social dialogue about negative health effects said to occur as a result of exposure to wind farm produced infrasound, sound below 20 Hz (Crichton et al., 2014a; Chapman et al., 2014; Rubin et al., 2014). Exposure to this narrative has been shown to increase concern about health effects of wind farms and create negative expectations leading to symptom reporting during periods of exposure to both genuine infrasound and sham infrasound (Crichton et al., 2014c). Importantly, elevated reports of annoyance and health effects have been shown to occur primarily in localities where there has been targeted publicity about the alleged harmful impacts of wind farms (e.g. Chapman et al., 2013). Thus exposure to a negative narrative about wind farms appears to be a stronger initiator of reported noise annoyance, than the inherent characteristics of the sound or the perceived noise sensitivity of residents.

Given that exposure to a negative narrative about wind farms may elevate noise annoyance, the converse may also be true; that accessing a positive narrative about wind farms may inhibit reported annoyance, even in those rating themselves as noise sensitive. If this were found to be the case this would have implications for the implementation of effective interventions and strategies to overcome annoyance reactions in those living in the vicinity of wind farms.

An experimental study was therefore designed to assess whether framing wind farm sound in either positive or negative ways would differentially influence annoyance reactions to that sound. The experiment was also devised to test whether exposure to wind farm sound was inherently annoying and whether the way in which the sound was described influenced associations between perceived noise sensitivity, and noise annoyance. Given the consistent relationship seen in the literature between negative affect and noise sensitivity, the relationship between noise sensitivity and negative mood was also assessed. Our primary hypothesis was that participants delivered negative expectations about wind farm sound, created from material available on the internet, would be significantly more annoyed during exposure to wind farm sound, than participants given positive expectations. We also hypothesised that positive expectation participants would experience very low levels of annoyance indicating that the sound was not inherently annoying. We further hypothesised that noise sensitivity would predict annoyance, but only in the negative expectation group.

2. Materials and method

2.1. Study design

The study received University of Auckland Human Participants Ethics Committee approval (reference number 8436). Recruitment was by way of a flyer placed on the University of Auckland website. Participants were informed that this was an experiment designed to assess subjective responses to wind farm sound and were blind to the hypotheses being tested. Given that this was an experiment testing noise annoyance, participants were also required to pass a threshold hearing screening test prior to experimental procedures. Sixty healthy student volunteers (21 male, 39 female) completed the experiment, which took place in a listening room constructed to international standards for the execution of subjective listening experiments (IEC268-13).

Participants were randomised to positive or negative expectation groups using a random number generator. The optimal sample size was evaluated employing G-Power (Faul et al., 2007), on the basis of analysis involving a 2 × 2 mixed design analysis of

variance to determine within and between group differences in relation to rated annoyance during two seven minute listening sessions. This power analysis indicated that with at least 54 participants (27 participants in each group), setting power at .95 and alpha at .05, it would be possible to detect a medium effect ($f=.25$) (Cohen, 1990). During listening sessions participants were simultaneously and continuously exposed to both infrasound and audible wind farm sound and were aware throughout that exposure was to wind farm sound containing audible and sub-audible components. Prior to exposure the negative expectation group watched a Digital Video Display (DVD) presentation which contained material found on the internet indicating that exposure to wind turbine sound, particularly infrasound, might present a health risk. Conversely, the positive expectation group viewed a DVD which framed wind farm sound positively and included information, also available on the internet, about the alleged health benefits of infrasound exposure. Participants received a NZ\$20 shopping voucher and were fully debriefed at the end of the study.

2.2. Materials

Audible wind farm sound, was transmitted at 43 dB during exposure sessions. This sound level was chosen as it was comparable to the maximum noise exposure level in New Zealand, set by the wind farm noise standard NZS 6808:2010. The sound recording was taken from a location on a small road approximately 1 km from the nearest turbine of a wind farm which consisted of 134 turbines (103 turbines rated power 660 kW and 31 turbines rated power 3 MW). The level of measured audible sound on location was 40 dB, indicating the sound was representative of a significantly exposed dwelling. Infrasound at 9 Hz was produced employing a combination of the Adobe[®] Audition software package with a Presonus[®] Firepod audio interface, and a Mackie[®] HR 150 active studio woofer, and was transmitted during listening sessions at 50.4 dB, to reflect as closely as possible the pressure level of 9 Hz measured in field studies 350 m from wind farms (Turnbull et al., 2012).

The negative expectation and positive DVDs were each of 5 min and 27 s duration. The negative expectation DVD set out concerns about wind farms sound exposure and integrated television current affairs footage, available on the internet, suggesting exposure to wind turbine sound, particularly infrasound, might pose a danger to health. The positive expectation DVD framed wind turbine sound as containing infrasound, sub-audible sound created by natural phenomena such as waves crashing on the shore and wind blowing through trees, which research has indicated could have health benefits (e.g. Yount et al., 2004). [Video scripts and sources of integrated internet materials are available from the authors].

2.3. Measures

The threshold hearing screening test was conducted using a Bay AudioCHEK Pro[®] headphone set, a specialised audiometry assessment tool designed to evaluate hearing detection at frequencies of 1 kHz; 2 kHz; 4 kHz; and 6 kHz.

In keeping with field studies (e.g. Pedersen and Persson Waye, 2007) noise sensitivity was evaluated at baseline on a 4 point scale from 1 (*not at all sensitive*), to 4 (*extremely noise sensitive*). Given consistent indications of a relationship between noise sensitivity and negative affect (e.g. Stansfield, 1992), participants also assessed their mood at baseline and during exposure sessions. Mood was assessed using 12 negative mood items (e.g. anxious, worried, tense, nervous, and distressed) and 12 positive mood items (e.g. calm, peaceful, cheerful, rested, and refreshed) evaluated on a seven point Likert scale ranging from 0 (*not at all*) to 6 (*extreme or extremely*). The effect of the manipulation on physical symptoms

has been explored in depth elsewhere (Crichton et al., 2014b). A negative mood score was calculated as the cumulative total of scores on negative mood items, and a positive mood score was assessed as the aggregate of scores on positive mood items.

The experience of annoyance was assessed during exposure sessions, whereby participants indicated the extent to which they found the experience of sound exposure unpleasant, annoying, and irritating, on a seven point scale from 0 (*not at all*) to 6 (*extremely*). For each exposure period, a total annoyance score was calculated as a cumulative total of ratings made for the three annoyance items. The reliability of the annoyance scale was confirmed with the annoyance scale demonstrating good internal consistency (Cronbach's $\alpha=.92$).

2.4. Data analysis

All statistical analyses were conducted using SPSS version 22 statistical software. To evaluate within and between group differences in relation to annoyance scores, assessed during exposure sessions, a mixed design analysis of variance (ANOVA) was performed. All p values in multiple comparisons were adjusted using Bonferroni corrections.

Using recommended strategies for evaluating continuous by categorical variable interactions (Dawson, 2014; West et al., 1996) hierarchical regression analysis was used to measure the main and interaction effects of noise sensitivity and expectation condition on annoyance and mood. In keeping with the recommended approach, noise sensitivity as a continuous predictor variable was mean-centred; expectation group, as a categorical variable, was dummy coded as 0 and 1; and the interaction variable noise sensitivity \times expectation was separately calculated, using the mean centred values, for inclusion at the last step of the regression. Preliminary analyses were undertaken to ensure the assumptions of normality, linearity, multicollinearity, and homoscedasticity were not violated.

3. Results

3.1. Annoyance

Firstly, a mixed design ANOVA was performed to evaluate within and between group differences in relation to annoyance, assessed during session one and session two. These data are depicted in Fig. 1. Analysis showed the experience of annoyance was influenced by group allocation; $F(158)=19.33$, $p<.001$, $\eta_p^2=.25$, so that negative expectation participants were significantly more annoyed than positive expectation participants during exposure sessions. More specifically, negative expectation participants were significantly more annoyed than positive expectation participants during both session one ($p=.001$) and session two ($p<.001$).

3.2. Noise sensitivity and noise annoyance

To assess whether subjective noise sensitivity directly influenced annoyance scores or moderated the relationship between expectation and annoyance, hierarchical regression analysis was undertaken. Regression results showed a main effect of expectations $b=4.87$, $SE(b)=.67$, $\beta=.56$, $t(56)=5.25$, $p<.001$, no main effect of noise sensitivity $b=-.43$, $SE(b)=.88$, $\beta=.07$, $t(56)=2.43$, $p=.63$, and a significant interaction between expectations and noise sensitivity $b=3.38$, $SE(b)=1.39$, $\beta=.34$, $t(56)=2.43$, $p=.018$ (results plotted in Fig. 2). To further confirm differences in the way in which noise sensitivity influenced noise annoyance, the analysis was run separately for each expectation group. Results confirmed noise sensitivity predicted noise annoyance in the negative

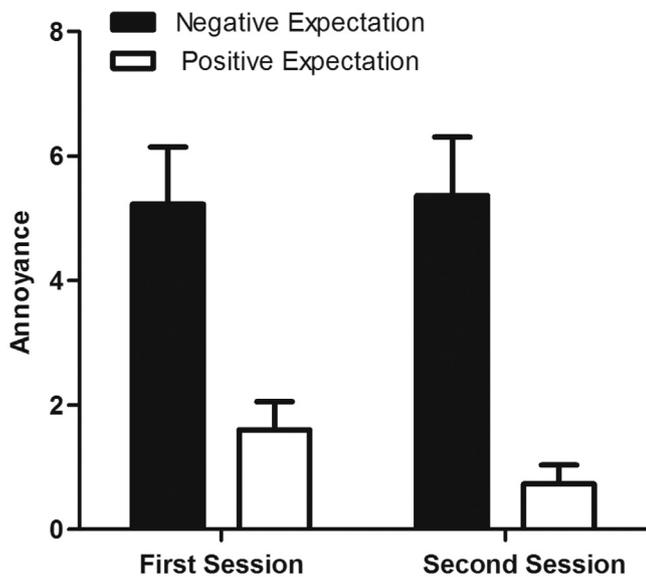


Fig. 1. Rated annoyance during wind farm sound exposure sessions.

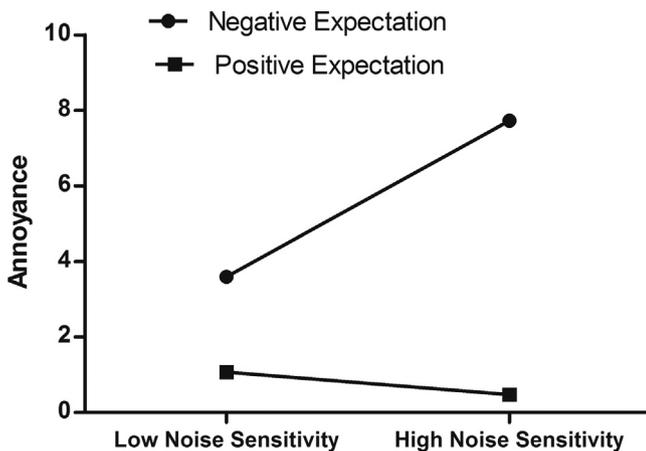


Fig. 2. The influence of noise sensitivity on the relationship between expectation and annoyance.

expectation group; $b=2.95$, $SE(b)=1.44$, $\beta=.34$, $t(28)=2.05$, $p=.05$, while noise sensitivity did not predict noise annoyance in the positive expectation group ($p > .05$).

3.3. Noise sensitivity and mood

To understand the influence of expectations and noise sensitivity on mood, hierarchical regression analysis was also undertaken. In relation to positive mood, although there was a main effect of expectations $b=-10.30$, $SE(b)=3.28$, $\beta=-.39$, $t(56)=-3.14$, $p=.003$, there was no main effect of either noise sensitivity, or any significant interaction between expectations and noise sensitivity. Therefore, noise sensitivity had no direct influence on positive mood, and did not moderate the relationship between expectations and positive mood. This can be contrasted with results found in relation to negative mood (results plotted in Fig. 3). In terms of negative mood, there was a main effect of expectations $b=8.75$, $SE(b)=2.23$, $\beta=.44$, $t(56)=3.93$, $p<.001$; no main effect of noise sensitivity $b=-3.36$, $SE(b)=2.07$, $\beta=-.24$, $t(56)=-1.62$, $p=.111$, and a significant interaction between expectations and noise sensitivity, $b=10.24$, $SE(b)=3.27$, $\beta=-.45$, $t(56)=-3.13$, $p=.003$.

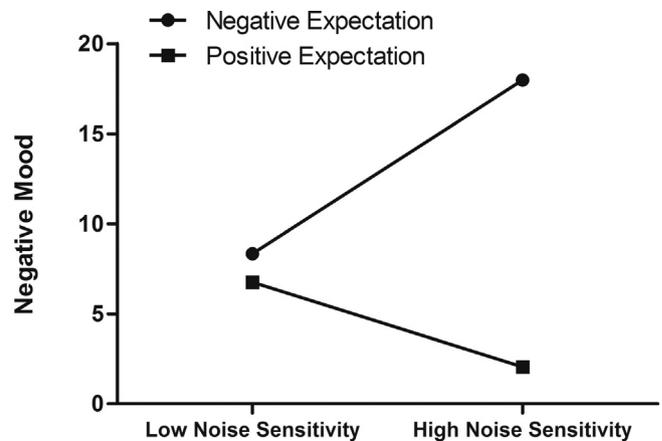


Fig. 3. The influence of noise sensitivity on the relationship between expectation and negative mood.

To further assess the way in which noise sensitivity influenced negative mood in each group, the analysis was run separately for each expectation group. Results confirmed noise sensitivity predicted negative mood in the negative expectation group; $b=6.89$, $SE(b)=3.05$, $\beta=.39$, $t(28)=2.26$, $p=.032$. Conversely, in the positive expectation group, there was an inverse relationship between noise sensitivity and negative mood $b=-3.36$, $SE(b)=1.54$, $\beta=-.38$, $t(28)=-2.18$, $p=.038$. Therefore noise sensitivity moderated the influence of positive and negative expectations on mood, in opposite directions. In the negative expectation group, participants rating themselves as more noise sensitive experienced greater negative mood during sound exposure, than participants rating themselves as less noise sensitive. Conversely, in the positive expectation group, participants rating themselves as more noise sensitive experienced less negative mood during sound exposure, than participants rating themselves as less noise sensitive.

4. Discussion

Findings provide encouraging evidence that positively framing environmental sound exposure has the potential to reduce annoyance responses in the community. In particular, we found that negative expectation participants were significantly more annoyed than positive expectation participants during exposure sessions, demonstrating that expectations influenced annoyance reactions. We also discovered that noise sensitivity moderated the relationship between negative expectations and the experience of annoyance, but did not influence annoyance in the positive expectation group. Finally, we determined noise sensitivity moderated the influence of positive and negative expectations on negative mood, in opposite directions.

Results showed that expectations about the health effects of sound shaped participants' experience of sound during exposure periods, highlighted by the fact negative expectation participants were significantly more annoyed by sound exposure than positive expectation participants. Findings are consistent with evidence indicating that negative attitudes to the noise source, and fear that the source of noise is dangerous, are associated with noise annoyance (e.g. Miedema and Vos, 1999; Pierrette et al., 2012; Weinstein, 1980). Results are also aligned with field research that shows wind turbine noise annoyance is strongly related to psychosocial factors, such as negative attitudes to wind turbines (Pedersen and Persson Waye, 2004; Pedersen et al., 2009).

The finding that negative expectation participants were significantly more annoyed than positive expectation participants might help explain the variability in noise annoyance reported in

field studies. If annoyance was purely a reflection of the character of wind farm sound, or of personality variables, such as noise sensitivity, we would not expect to see substantial variations in the percentage of people reporting noise annoyance across geographical locations. Most recently a thorough investigation by Health Canada, in relation to two Canadian provinces with equivalent residential noise exposure, showed 6.3% of Prince Edward Island respondents were highly annoyed by wind turbine noise compared with 16.5% of respondents from Ontario. (Health Canada, 2014). Further, results from cross-sectional studies in Sweden and the Netherlands indicated 10–20% of respondents living in proximity to wind farms found wind turbine noise annoying, and 6% of respondents found wind turbine noise very annoying, at 35–40 dB exposure (Pedersen and Persson Waye, 2004, 2007; Pedersen et al., 2009), while, in contrast, 59% of respondents reported noise annoyance in a New Zealand study (Shepherd et al., 2011). The New Zealand study was conducted at a time during which there had been adverse publicity concerning the expected adverse effects of living in proximity to the particular wind farm in question, including recent national television news coverage (Owen and Campbell, 2009).

That positive expectation participants were generally not annoyed by wind farm sound exposure further indicates that the fluctuating nature of the wind farm sound, to which the participants were exposed, did not make it intrinsically annoying or unpleasant. This is in line with experimental work indicating that when exposed to wind farm sound, not being aware of the source of sound is associated with reduced noise annoyance (Van Ren-terghem et al., 2013). Our experiment showed that when the sound was portrayed positively and associated with nature sounds containing sub-audible infrasound and audible swishing or lapping characteristics, such as ocean waves, participants were significantly less annoyed by wind farm sound. Findings are coherent with an experimental study in which participants exposed to pink noise were significantly more annoyed when shown a picture of a large factory prior to noise exposure, than when shown a picture of a waterfall (Bergman et al., 2008). Thus the meaning ascribed to a sound appears to have a powerful role in determining annoyance reactions, further suggesting that creating a positive context for environmental sound exposure is likely to minimise noise annoyance.

That noise sensitivity predicted annoyance in the negative expectation group indicates that subjectively noise sensitive individuals are more open to negative suggestions about sound exposure, indicating the likelihood that, in the community, this group are more at risk for negative reactions triggered by the dissemination of negative information about wind farms. That noise sensitivity did not predict noise annoyance when participants listened to wind farm sound in a positive context is a promising finding reflected in field research. A cross-sectional study conducted in The Netherlands, demonstrated that respondents who benefited economically from wind turbines were less annoyed by wind turbine noise than other respondents, despite exposure to higher sound levels, and notwithstanding perceived noise sensitivity (Pedersen et al., 2009). This supports evidence in the current study that perceived noise sensitivity does not inexorably lead to annoyance reactions and that the context of sound exposure influences the relationship between perceived sensitivity and annoyance. This provides indications that perceived noise sensitivity is not a barrier to the success of interventions to reduce noise annoyance, and that annoyance reactions to wind farm sound can be minimised even in noise sensitive individuals.

Findings also demonstrated that high noise sensitivity participants experienced greater negative mood during noise exposure when given a negative narrative about sound exposure. However, in the positive expectations group, negative mood was inversely

correlated with noise sensitivity. This suggests that positive expectation participants, who perceived themselves to be noise sensitive, experienced relief from an underlying tendency to be anxious about the negative effects of sound exposure, reflected in low levels of negative mood while listening to wind farm sound. This supports the concept that perceived noise sensitivity predominantly reflects attitudinal and evaluative responses to sound, rather than sensory aspects of auditory processing (Ellermeier et al., 2001), and that context has a pivotal impact on the influence of noise sensitivity upon reactions to sound (Smith, 2003). Noise annoyance has been described as a phenomenon of mind and mood (Stallen, 1999). Thus indications that positive expectations can reduce negative mood in noise sensitive individuals, provides further evidence that exposure to a positive narrative about wind farm sound may ameliorate annoyance reactions, despite perceived noise sensitivity.

It is a study limitation that it was not possible to assess reactions to sound in the absence of a positive or negative narrative, given there was not a third group experiencing the sound without receiving pre-exposure information. It is a further limitation of the study that reactions to exposure to audible sound recorded from a wind farm played in conjunction with infrasound produced in a studio, may not be entirely transferrable to the experience of residents living in the vicinity of wind farms. It may also be particularly challenging to frame wind farm sound positively in wind farm neighbourhoods where residents are currently exposed to negative views or threat perceptions about sound, or there is intra-community conflict about wind farms which is causing disquiet (Walker et al., 2015). However, there are promising indications that symptomatic experiences triggered by negative expectations about wind farm sound can be reversed by delivering positive information about wind farms (Crichton and Petrie, 2015a), or by providing a reassuring alternative explanation for symptoms (Crichton and Petrie, 2015b). Future research should now extend to investigating whether the positive portrayal of wind farms sound has an influence on annoyance reactions during exposure to wind farm sound in real world settings, and whether annoyance reactions can be reduced in people already influenced by exposure to a negative narrative about wind farms.

Research shows that, throughout the world, current guidelines for siting wind turbines are effective to protect against direct health effects from audible noise, including low frequency noise, as well as infrasound (Berger et al., 2015). However, as evidence illustrates that some people are annoyed by wind farm sound which is associated with the experience of symptoms of psychological distress (Bakker et al., 2012), the design and implementation of interventions to minimise noise annoyance should become an important adjunct to policies for wind farm development. Given research shows the dissemination of misinformation about wind farm sound is elevating annoyance reactions, it is also incumbent on the popular media to responsibly report on issues relating to wind farms, rather than emphasising fright factors producing fear, anxiety and concern (Deignan et al., 2013). Indications are that portraying wind farm sound positively should reduce annoyance reactions, and that both the acoustic characteristics of wind farm sound and the perceived noise sensitivity of local residents should not implicitly preclude the success of interventions designed to minimise annoyance.

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