Understanding park visitors' soundscape perception using subjective and objective measurement (#89001)

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Understanding park visitors' soundscape perception using subjective and objective measurement

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Environmental noise knows no boundaries, affecting even protected areas. Noise pollution, originating from both external and internal sources, imposes costs on these areas. It is associated with adverse health effects, while natural sounds contribute to cognitive and emotional improvements as ecosystem services. When it comes to parks, individual visitors hold unique perceptions of soundscapes, which can be shaped by various factors such as their motivations for visiting, personal norms, attitudes towards specific sounds, and expectations. In this study, we utilized linear models and geospatial data to evaluate how visitors' personal norms and attitudes, the park's acoustic environment, visitor counts, and the acoustic environment of visitors' neighborhoods influenced their perception of soundscapes at Muir Woods National Monument. Our findings indicate that visitors' subjective experiences had a greater impact on their perception of the park's soundscape compared to purely acoustic factors like sound level of the park itself. Specifically, we found that motivations to hear natural sounds, interference caused by noise, sensitivity to noise, and the sound levels of visitors' home neighborhoods influenced visitors' perception of the park's soundscape. Understanding how personal factors shape visitors' soundscape perception can assist urban and non-urban park planners in effectively managing visitor experiences and expectations.

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Abstract

Environmental noise knows no boundaries, affecting even protected areas. Noise pollution, originating from both external and internal sources, imposes costs on these areas. It is associated with adverse health effects, while natural sounds contribute to cognitive and emotional improvements as ecosystem services. When it comes to parks, individual visitors hold unique perceptions of soundscapes, which can be shaped by various factors such as their motivations for visiting, personal norms, attitudes towards specific sounds, and expectations. In this study, we utilized linear models and geospatial data to evaluate how visitors' personal norms and attitudes, the park's acoustic environment, visitor counts, and the acoustic environment of visitors' neighborhoods influenced their perception of soundscapes at Muir Woods National Monument. Our findings indicate that visitors' subjective experiences had a greater impact on their perception of the park's soundscape compared to purely acoustic factors like sound level of the park itself. Specifically, we found that motivations to hear natural sounds, interference caused by noise, sensitivity to noise, and the sound levels of visitors’ home neighborhoods influenced visitors' perception of the park's soundscape. Understanding how personal factors shape visitors' soundscape perception can assist urban and non-urban park planners in effectively managing visitor experiences and expectations.

Keywords: soundscapes, ecosystem services, geospatial, human perception, parks and protected areas

Introduction

More than eighty percent of the contiguous United States has elevated sound pressure levels caused by anthropogenic sources (Mennitt, Fristrup, Sherrill, & Nelson, 2013). Extensive exposure to noise at high levels can negatively affect human health by elevating blood pressure levels and promoting stress and heart disease (Goines & Hagler, 2007; Hammer, Swinburn, & Neitzel, 2014). Utilizing U.S. EPA (Environmental Protection Agency) estimates from 1981 and adjusting them to the U.S. population (Census Bureau, 2010), 145.5 million people are potentially at risk of developing hypertension as a result of noise (Hammer et al., 2014).

Parks and protected areas serve as places where visitors can find refuge from industrial and community noise. However, a study found that 63% of protected areas experience a doubling of background sound levels due to anthropogenic sources and 21% experience a 10-fold increase (Buxton et al., 2017). Thus, protecting natural sounds in parks is important, especially as many visitors to parks and protected areas seek natural sound experiences as a sanctuary from potentially loud and noisy soundscapes they might experience during the course of their daily lives.

Humans have an innate biological association to the natural world (Wilson, 1984) that is also of value for healing the mind and body, as captured by famous nature writers such as Muir (1901; 1979) and Thoreau (1854), as well as, documented by many researchers across disciplines (Abbott, Taff, Newman, Benfield, & Mowen, 2016; Benfield, Taff, Newman, & Smyth, 2014; Kaplan, 1995; Wilson, 2001). The positive relationship between human health and spending time in nature can promote improved memory retention (Holden & Mercer, 2014) and overall psychological wellbeing (Bratman, Hamilton, & Daily, 2012). Experiences in nature can facilitate recovery from mental fatigue (Kaplan, 1995) and a reduction in repetitive negative thoughts (Bratman, Hamilton, Hahn, Daily, & Gross, 2015). Multiple senses are stimulated by natural environments, with natural sound being an important factor (Franco, Shanahan, & Fuller, 2017).

Noise can negatively impact both humans and wildlife (Francis & Barber, 2013; Barber, Crooks, Fristrip, 2010; Goines & Hagler, 2007; Pilcher, Newman, & Manning, 2007; Stack, Newman, Manning, & Fristrup, 2011). For wildlife, negative effects of noise may include difficulty in finding a mate and detecting prey or predators, and increased stress (Francis & Barber, 2013). For humans, excessive exposure to environmental noise can cause negative health outcomes such as stress, inadequate sleep, heart disease and hearing loss (Hammer et al., 2014). Hammer et al. (2014), estimate that a large portion of U.S. residents are subject to higher levels of noise and therefore subject to noise-related health problems. Urban soundscape sources such as aircraft, traffic, and people talking have been found to interfere with memory (Benfield et al., 2010), lead to increased stress and lower cognitive ability (Cohen et al.,1980) and cause elevated stress levels in both adults and infants (Cantuaria et al., 2018). Currently about 80% of the U.S. population resides in urban areas and it has been estimated that by 2050, 90% of the population will live in urban areas (United Nations, 2018). As our society continues to urbanize, the risk for prolonged exposure to loud anthropogenic sounds will rise.

In contrast to the negative impacts related to urban noise exposure, there appear to be many positive benefits or psychological ecosystem services related to exposure to natural sounds (Francis et al., 2017). Natural soundscapes are important resources to the health and well-being of both humans and wildlife (Francis et al., 2017). For wildlife, natural sounds play an important role in reproduction, safety and the detection of prey (Francis et al., 2017). For humans, natural sounds improve human cognition (Abbott et al., 2016), enhance positive moods (Benfield et al., 2014), and increase recovery from stress (Alvarsson, Wiens, & Nilsson, 2010). Ferraro et al., (2020) found that park visitors who were exposed to an experimental treatment of increased bird chorus, had increased psychological restoration. For most visitors to parks and protected areas, hearing the sounds of nature and experiencing natural quiet are important motivations for their visit (Haas & Wakefield, 1998; Outdoor Industry Report, 2017). As visitation to parks increase, so does noise from transportation and other visitors (Levenhagen et al., 2020; NPS, 2010). As a result, National Parks have plans and polices in place to protect, maintain and restore natural sounds and quiet for both visitor and wildlife health and wellbeing (e.g., the Director's Order #47, Soundscape Preservation and Noise Management, 2000).

The relationship between humans and soundscapes is complex. For example, increased sound levels (e.g. transportation and other human-made sounds) correlate with decreased housing values (Baranzini, Ramirez, Schaerer, & Thalmann, 2008; Theebe, 2004; Trojanek, Tanas, Raslanas, & Banaitis, 2017). Conversely, increased bird diversity is related to higher housing values (Farmer, Wallace, & Shiroya, 2013). There are also positive links between bird species diversity and increased measures of life satisfaction in Europe (Methorst et al., 2021). Ferraro et al., (2020) found that hikers who perceive higher levels of biodiversity through hearing also had increased perceptions of psychological restoration. This phenomenon relates to the proposed coupling of human and natural systems through soundscapes (Francis et al., 2017), which suggests that the soundscape mediates feedbacks between humans, their behavior and wellbeing and ecological systems and biodiversity.

To understand the complexity of soundscapes, geospatial data is increasingly used to capture the impact of noise and natural sounds on landscapes (e.g. noise impacts throughout the contiguous United States (Mennitt et al., 2016)). Geospatial data depicting sound pressure level have shown how sound sources such a traffic (e.g. transportation noise (Miller, 2003)), construction (Hong & Jeon, 2014; (Lee, Chang, & Park, 2008) are dispersed across landscapes, plus the pervasiveness of noise pollution in U.S. protected areas (Buxton et al., 2017). These data have also been used to assess racial, ethnic, and social inequalities in relation to noise pollution (Casey et al., 2017). Neighborhood sound levels can be used to answer a variety of questions pertaining to health and the environment. For example, using aircraft noise contours paired with zip code blocks, Andrew et al. (2013) identified a correlation between risk of cardiovascular disease in older adults and proximity of their residence to an airport. Additionally, geospatial data are used to measure exposure, as well as, identify problem areas where mitigation is needed (Aletta & Kang, 2015; Brown, 2012) and have been useful for developing policies that aim to regulate and manage noise (Murphy & King, 2010) so as to minimize negative impacts (Aletta & Kang, 2015; Cai, Zou, Xie, & Ma, 2015; Hong & Jeon, 2014; Lee et al., 2008; Liu, Kang, Luo, Behm, & Coppack, 2013; Shavelson, 2004).

Several studies have explored non-acoustic factors that influence perceptions of soundscapes in a park setting (Benfield, et al., 2014; Marin, Newman, Manning, Vaske, & Stack, 2010) and in environmental noise assessments (Liu, Kang, Behm, & Luo, 2014; Miedema & Vos, 1999;1; Schomer, Mestre, Schulte-Fortkamp, & Boyle, 2013). Marin et al. (2011) found that motivations can influence visitors' perceptions of the soundscape in urban parks. Another study determined that landscape spatial patterns influence soundscape perceptions (e.g. density of vegetation and built environment) (Liu et al., 2014). Motivations (Marin et al., 2011) and noise sensitivity (Benfield, et al., 2014) can also predict visitors' perceptions of the soundscape they experience in National Parks. Surprisingly, no study has explored the role of visitors' home neighborhood sound exposure in predicting attitudes towards park soundscapes. Sounds experienced in daily life may influence tolerances to different sources of sound, expectations for the acoustic properties of soundscapes in protected areas, plus motivations for visiting locations where the sonic environment contrasts strongly from that of the routine.

Environmental noise researchers are interested in exploring non-acoustic variables that predict how individuals or communities might respond to noise from airplanes, trains, highway traffic or urban environments. While sound level meters measure objective physical components of the acoustic environment, human perception of sound varies amongst individuals, communities, and circumstances. Miedema and Vos (1999) found that noise sensitivity and fear of noise sources have a large influence on noise perception. Studies that examine the influence of wind turbine noise on communities have found that attitudes towards wind turbines and other social factors are stronger predictors of noise annoyance than the sound level of wind turbines themselves (Haac et al., 2019; Song, Di, Xu, & Chen, 2016). Schomer at al. (2013) points out that non-acoustic factors explain a large amount of how communities respond to noise.

Here, we sought to understand what factors influence Muir Woods National Monument (MUWO) visitors' perceptions of park soundscapes. We used a questionnaire to gather information about visitors' perceptions of the park soundscape, as well as personal attitudes and norms. Based on the outcomes from earlier studies, we predicated that individuals' motivations (Marin et al., 2011) and noise sensitivity (Benfield et al. 2014) would influence visitors' perceptions of the park's soundscape. We created a measure that asked visitors how much noise interfered with their ability to hear natural sounds in the park and we predicted that this measure would also influence perceptions of the soundscape. We included the park's sound level in our analysis, which is often a factor in soundscape perception (Jeon & Hong, 2015). Additionally, we included the density of visitors on the trail in our analysis. We predicted that this may influence the amount of noise and perceptions of natural sounds. Finally, to explore the role of the sound level of visitors' neighborhood acoustic environment in explaining perceptions, geospatial data was used to assess sound pressure levels of the zip code areas provided by respondents.

Materials & Methods

The analysis presented in this paper is part of a larger study. The primary purpose of the larger study was to explore the coupling of the natural and human environments through the soundscape, via a paired experiment at Muir Woods National Monument (MUWO). Detailed methods and information about the larger study can be found in Levenhagen et al. (2020). Field data collection was approved by the US Department of the Interior (Permit #: MUWO-2016-SCI-0001).

Study Area. We conducted this study at MUWO, the first urban National Monument located 25 km north of San Francisco, California, and a popular destination for tourists that includes hiking trails throughout 500 acres of coast redwood trees (Sequoia sempervirens). People are drawn to this park to experience the towering and awe-inspiring old growth coast redwood forest. Visitation to the park has been steadily increasing and ~~exceeds~~ one million visitors per year (NPS, 2017). Due to the high visitation rates at this relatively small park, reservations are now required for all personal vehicles and shuttle riders visiting MUWO. For visitors who choose to ride the shuttle, a ticket can be reserved in advance and they can park free of charge 13 km away (in either Sausalito or Mill Valley, California). Shuttles run every half hour from 8:30am to 5:00pm. Protecting natural soundscapes is a primary management objective at MUWO. Since 2005 the park has supported a variety of soundscape studies (Marin et al., 2011; Pilcher et al., 2009; Stack, Peter, Manning, & Fristrup, 2011a) that examined the effectiveness of trail signage to reduce visitor noise (Stack et al., 2011). Due to the findings from Stack et al., (2011) the park now has a "quiet zone" in the Cathedral Grove area of the park.

Experimental Design and Acoustic Measures. We expanded on methods used by Stack et al. (2011) and used educational treatments to designate "quiet days" (treatment) and "control days" during the study period. Stack et al. (2011) tested signage in one small area of MUWO, while our project spanned the entire trail system. We used treatment and control mitigations in weeklong blocks. Additionally, we had rangers enforce the quiet periods. MUWO had one main entrance, which likely made the enforcement more effective than parks with distributed entrances. During the treatment or "quiet" days, 19 educational A-frame signs (e.g., 'Enter Quietly', 'Maintain Natural Quiet', 'What you can do to help natural soundscapes') were placed along a ~0.6 km segment of the main trail system. During control days, all educational signs related to maintaining quiet were removed or covered. Additional details related to the experimental design can be found in Levenhagen et al. (2020).

To test the effects of the treatment on background sounds in MUWO, we deployed acoustic recording devices (13 Roland R05) along the same ~0.6 km segment of the main trail system. The 50th percentile A-weighted sound pressure level (the L_{50} in dBA) was calculated from recordings of each device for each hour (see Levenhagen et al., 2020 for details).To test the influence of the park's sound level on visitors' perception of the park soundscape, we paired survey data with the average hourly L_{50} from the nine acoustic recording devices that were within 50 meters of the trail. The hourly L_{50} was matched with survey responses based on the hour in which the survey was administered.

Visitor Use Estimation. For this project, we estimated the number of visitors using the trail during the time that respondents were visiting the park. Automated infrared visitor monitors, TrailMaster (TM1550), were deployed at the same 13 trail locations as the acoustic recording devices. These are not cameras and only detect the infrared wavelength that people emit as they walk by the device. Data were logged continuously from May 9th through May 21st, 2016. Because automatic trail counter estimates can vary with position, angle, etc, a member of the research team observed and manually counted visitors on the trail to calibrate each automated counter. During the study period, each trail counter was calibrated for a total of 12 hours (Pettebone, Newman, & Lawson, 2010). Manual count calibrations occurred in one-hour blocks, on randomly chosen days throughout the study period.

For this analysis, we used the trail counter closest to the entrance (also closest to the survey intercept location) to estimate the number of visitors on the trail. For most visitors, this location is used as an entrance and exit for the trail system. An adjustment factor was calculated by dividing the number of observed visitor pass-by events manually counted during the calibration period by the number of events counted by the automatic monitor. That number was then divided into two, because the monitor location is both an entrance and exit. The mean number of visitors for each one-hour block of time was calculated and multiplied by the final adjustment factor. Visitor estimates were matched with survey data based on the estimated visitor count from the hour of the timestamp on the survey responses.

Survey Data. The research team collected a total of 537 surveys between May 9th and 21st, 2016 as visitors were exiting the park. All survey respondents verbally consented to participating in the survey. The survey evaluated the effectiveness of realistic management solutions to improve environmental conditions for wildlife and visitor experiences in MUWO. In addition, we collected data on the tradeoffs visitors would be willing to make in order to achieve a high-quality acoustic experience (Newman, Manning, Dennis, & McKonly, 2005). For the purpose of this paper, we focused on questions specific to visitors' perceptions of the soundscape in MUWO that capture pleasantness, noise sensitivity and noise interference (Table 1). In addition, we asked visitors where they came from by including a zip code. This work was approved by the Institutional Review Board of Pennsylvania State University (protocol#: 00004937).

(Insert Table 1 here)

Pleasantness For this study, we wanted to test a broad scale that incorporates a positive, well understood attitude towards sound, referred to as pleasantness (Schomer et al., 201 which has been found to be an important indicator in measuring urban and rural soundscape perceptions (De Coensel & Botteldooren, 2007). We measured pleasantness of the soundscape on a 6-point categorical scale from very unpleasant to very pleasant.

Noise Sensitivity Scale A shortened field version of the Noise Sensitivity Scale (NSS) can be used to measure individuals' response to noise in their everyday lives and has been empirically validated (Benfield, et al., 2014). We calculated the NSS score after reverse coding one of the items, "I get used to most noises without much difficulty", to create an overall noise sensitivity score for each respondent. We summated items from the noise sensitivity scale . Lower values indicate a decreased aversion and higher tolerance to noise and higher values indicate increased aversion and lower tolerance to noise. We measured noise sensitivity items on a 6-point scale.

Noise Interference We developed a measure to investigate respondents' self-report of how often noise interfered with hearing natural sounds or the degree to which natural sounds were masked by anthropogenic sounds. The higher the value, the more interference from human-made sounds the respondent reported experiencing in MUWO. We measured noise interference on a 5-point scale.

Natural Sound Motivation Recreation Experience Preference (REP) Scales are used to measure park visitors' motivations or the desired outcomes they seek in a park or protected area (Manfredo, Driver, & Tarrant, 1996). For this study, we were only interested in REP scales related to natural sounds. Prior to calculating the natural sound motivation variable, the four separate items were tested for reliability (Table 2). The natural sound motivation variable was created by summing the four motivation questions related to natural sounds. Internal consistency of the items was assessed using Cronbach's alpha. The reliability analysis indicated an acceptable level of internal consistency (α=.859) (Vaske, 2008).

(Insert Table 2 here)

Visitors' neighborhood sound level. We obtained acoustic data from Mennitt et al. (2016), which approximates the existing L50 sound level at 270 m resolution across the United States during a typical day. We calculated the neighborhood sound level based on the boundary of respondents' home zip code. For each visitor's home zip code, the mean sound level was obtained by calculating an average sound level from all grid cells within the zip code. Zip code boundaries were obtained from the United States Census data (Census Bureau, 2015) and matched to zip codes reported by visitors. A total of 441 unique zip codes were reported by survey respondents. Of these 372 zip codes matched with the boundary shapefile obtained from the Census Bureau and were used for the remainder of the study (Figure 1). We discarded unmatched zip codes as these may have been entered incorrectly. In addition to understanding neighborhood acoustic environments, we used zip codes summarized by state and metropolitan area to better understand where people came from to visit the park. Data on metropolitan areas were obtained from the Census Bureau to identify urban-rural areas where Urbanized Areas (UAs) are defined as areas with 50,000 or more people and Urban Clusters (UCs) are areas with at least 2,500 and less than 50,000 people (Census Bureau, 2016). We performed all geospatial tasks in ArcMap 10.4 (ESRI, 2011).

(Insert Figure 1 here)

Data Analysis. Given the potential for spatial autocorrelation in the relationship between perceptions of soundscape pleasantness and neighborhood zip code sound levels, in preliminary models we used the fitme function in the spaMM package (Rousset & Ferdy, 2014) in R to incorporate an exponential spatial correlation structure using the Matérn correlation function (e.g., Senzaki et al. 2021; Wilson et al., 2021). We also included hour of the survey nested within day as random intercepts in the model to account for hierarchical sampling approach. In these and subsequent models we assumed Gaussian error and transformed pleasantness with a Tukey transformation to improve model fit. There was no evidence that inclusion of the spatial autocorrelation structure or hour nested within day as random effects improved model fit over models that did not have these terms, thus they were removed from the analysis following Bates et al. (2015). As such, we used multiple linear regression in all subsequent models.

For formal model selection we began with a model with neighborhood sound level as the single predictor for soundscape pleasantness and sequentially added additional predictor variables. Models with additional variables were retained over the previous hypothesized model if the fixed effects had a p-value < 0.05 and if the Akaike Information Criterion (AIC) was reduced by >2 from the previously model. We confirmed the final model met model assumptions by visually inspecting diagnostic plots and also checked for potential issues of multicollinearity among predictors using the check_collinearity function in the performance package (Lüdecke, Ben-Shachar, Patil, Waggoner, & Makowski (2021)) in R, but found none.

Results

Sample characteristics and neighborhood sounds level. During May 2016 we found that 82% of the visitors to Muir Woods were from the United States, 15% were international and 3% unknown. Within the United States, visitors came from 46 different states, with the majority coming from California (30%). Twelve percent of the population were from nearby large urban areas such as San Francisco or Oakland (Figure 3). Moreover, a significant portion of the sample reported being from an urban area (77%), while the other 23% were from rural locations. Almost half of the sample (48%) reported living 4,000 miles or more from the park and 20% of the sample live 100 miles or less from the park. Only 6 respondents lived 10 miles or less from MUWO.

The minimum mean L_{50} of respondents' zip codes was 31 dBA (the sound level of a soft whisper or light wind) and the maximum mean was 57 dBA (the sound level of heavy traffic) (Figure 2). On average, the mean sound level for respondents' zip codes was 47 dBA, which is comparable to the sound level of a quiet residential or urban neighborhood during the day.

(insert figure 2 here)

Figure 2. Distribution of visitors' neighborhood sound levels

(Insert figure 3 here)

Figure 3. Distribution of visitors by rural and urban neighborhoods

Descriptive statistics. The top ranked motivation for visiting Muir Woods was "seeing the redwoods" and the second was "appreciating the scenic beauty". The third most important motivation for visiting the park was "to enjoy the natural quiet and sounds of nature", with a mean rating of 4.08 (on a scale from one to five) (Table 2). Most visitors rated "hearing quiet and sounds of nature" as very important to their visit. To better understand how visitors' motivations related to soundscape pleasantness, the motivation items related to sound were combined into one motivation score. Overall, these items have a relatively high internal consistency (α = .859). The mean score for the combined sound motivation is 3.83 on a 5-point scale, meaning that on average, visitors rated items related to hearing natural sounds as important to their visit to MUWO.

Results from the noise sensitivity scale indicated that there was relatively high internal consistency within items (α = .808). To create an overall noise sensitivity score for each visitor, the items were summated. The minimum score was one (low noise sensitivity) and the highest score was six (high noise sensitivity). The mean noise sensitivity score for visitors was 4.10, meaning that the sample of visitors trend towards being sensitive to noise. For the measure of soundscape pleasantness, the mean score was 5.24 (6-point scale), meaning that the sample on average rated the soundscape as pleasant. Finally, for noise interference, the mean score was 2.37 (5-point scale). This means that on average, visitors were able to hear natural sounds usually or sometimes clearly without interference from human-made sounds.

Linear model explaining soundscape pleasantness in MUWO. Model selection resulted in a model where pleasantness was explained by neighborhood sound level, noise sensitivity, noise interference and sound motivation (Tables 3, 4 and Figure 4). These variables explain 24% of the variance in soundscape pleasantness (Multiple R^2=0.24). Based on the marginal effects from the model (using the untransformed dependent variable), a 1 dB increase in neighborhood sound level results in a 0.02 decrease in the rating of perceived pleasantness (6-point scale) of the soundscape (Figure 4). A one-point increase in noise interference resulted in a 0.41 decrease in pleasantness of the soundscape (Figure 4). A one-point increase in noise sensitivity resulted in a 0.14 decrease in pleasantness of the soundscape (Figure 4). Finally, a one-point increase in motivation to hear natural sounds resulted in a 0.09 increase in pleasantness of the soundscape (Figure 4).

(Insert Table 3 here)

(Insert Table 4 here)

***Post hoc* analysis of predictor variables.** We used *post hoc* linear models to explore potential predictors of noise interference and noise sensitivity. They were the strongest predictors of pleasantness and we wanted to know more about how they related to the other independent variables in the final model. We created linear models using noise sensitivity as a dependent variable and all of our hypothesized independent variables. We did the same for noise interference. We found that neighborhood sound level had a small, but significant, negative influence on noise sensitivity (Table 5). We also created a scatter plot (Figure 5) that represents the marginal effects of neighborhood sound level and noise sensitivity. Sound motivation had a small, significant and positive effect on noise sensitivity (Table 5). Sound motivation was also a significant predictor of noise interference, along with quiet v. control days (Table 6).

(insert figure 4)

Figure 4. Marginal effects using the final model (Pleasantness ~ Neighborhood sound level + noise sensitivity + noise interference + sound motivation). (a)Marginal effect of noise sensitivity on pleasantness; (b) Marginal effect of noise interference on pleasantness; (c) Marginal effect of neighborhood sound level on pleasantness; (d) Marginal effect of sound motivation on pleasantness.

(insert table 5)

(insert table 6)

(Insert Figure 5)
Figure 5. Marginal effects of noise sensitivity and neighborhood sound level

Discussion

We found a combination of different factors influenced visitors' perception of the pleasantness of the soundscape in a park context. Noise interference, noise sensitivity, motivation to hear natural sounds, and sound level of visitor's neighborhood were significant predictors of soundscape pleasantness. More objective measures, like the sound level of the park and the number of visitors on the trail were not significant variables in our multiple regression model.

Noise interference. A number of studies have focused on the influence of motorized sounds on soundscape experience (e.g., Benfield, Taff, Weinzimmer, & Newman, 2018; Mace, Bell, & Loomis, 2004; Mace, Corser, Zitting, & Denison, 2013; Weinzimmer et al., 2014). Our study expands this research to highlight the impact of anthropogenic sound sources such as voices, speakers playing music, and park maintenance machinery, on negative soundscape experiences. Model results show a significant negative relationship between subjects' rating of noise interference and pleasantness of the soundscape. This factor had the largest effect on pleasantness in the model (Table 4). As the interference with natural sounds increased, the perception of soundscape pleasantness decreased. Based on previous measures of the MUWO soundscape, visitors talking is the most prevalent anthropogenic sound and has the potential to mask or overpower natural sounds (Stack et al., 2011a). Hong and Jeon (2014) also found a negative relationship between human sounds and pleasantness, but in an urban context. In a lab study, Benfield et al. (2010) found that hearing recordings of voices have a negative effect on participants' ratings of national park scenes. Additionally, the increased volume of voice sounds led to increased ratings of annoyance and negatively affected emotional ratings tranquility, freedom, and naturalness (Pilcher, Newman, & Manning, 2009).

Our results suggest that the sound level of the park was not a significant predictor of soundscape pleasantness. Noise interference, rather than the acoustic measure of the environment's sound pressure level, better explained the perception of the soundscape. When a person interprets a sound, it can be the sound source, rather than the sound pressure level that might elicit a positive or negative interpretation or reaction (Alvarez, Angelakis, & Rindel, 2006). The sound level of the park includes both natural and anthropogenic sounds. Moving water was a dominant sound captured by many of acoustic recording devices during the sampling period, which is a sound that most people find pleasing. Noise interference was more accurate in predicting how visitors rate the soundscape. Additionally, Benfield et al. (2014) found that study participants who listened to natural sounds had improved health measures compared to participants who listened to anthropogenic sound sources at the same sound level. These findings differ from Levenhagen et al., (2020) which found hourly sound level to be a significant predictor for proportional odds ratios for pleasantness. Our results are not conflicting, rather in this paper we used linear regression modeling to understand variables that predict pleasantness; thus, the assumptions and results here are different from Levenhagen et al., (2020). Additionally, the dataset used in this paper differs slightly from Levenhagen et al. (2020) because we only included visitors' responses whose zip codes matched with the US Census shapefile.

Another notable finding in our study is that the educational signs or the experimental design are not a significant predictor of soundscape pleasantness. It could have been hypothesized that on days when signs were present, visitors would have been quieter, thus improving soundscape pleasantness. This assumption is supported in our *post hoc* analyses for noise interference (Table 6). Signs (quiet v. control) were significant predictors of noise interference. The direction of this relationship is positive, suggesting that with when quiet signs were covered, ratings of noise interference increased. Levenhagen et al., (2020) used the same dataset to examine perceptions of biodiversity and found that an interaction between the educational signs and actual bird diversity were significant in predicting perceptions of bird diversity. When the study area was quieted with the treatment of educational signs, visitors were better able to observe bird diversity.

Noise sensitivity. We found noise sensitivity to be a significant predictor of soundscape pleasantness. Specifically, those who were more sensitive to noise found the soundscape to be less pleasant. However, the influence of noise sensitivity on pleasantness was not as strong as the influence of noise interference (Table 4). ~~Nevertheless, this~~ relationship is consistent with data from Rocky Mountain National Park. Benfield et al. (2014), found that park visitors with higher ratings of noise sensitivity rated aircraft noise as less acceptable and rated other human-made noises as more problematic. We used a post hoc linear model to learn more about predictors of noise sensitivity. Neighborhood sound level had a small negative, but significant effect in predicating noise sensitivity. Figure 5 is a visual representation of this small, but negative relationship. In other words, noise sensitivity decreases as the neighborhood sound level increases. It makes sense that these two variables would be related and it would be valuable to understand more about why they are related. Are people from loud neighborhoods less sensitive to noise because they are accustomed to it? Or do people that are sensitive to noise choose to live in quieter areas?

Sound Motivation. Motivation to hear natural sounds was a positive and significant predictor of soundscape pleasantness. The important relationship between visitor motivations and perception of the soundscape was consistent with Marin et al. (2011), who determined visitors to Muir Woods with higher motivations to experience quiet had lower ratings of human caused noise. This also reflects findings in our post hoc analysis. We determined a small positive relationship between sound motivation and noise sensitivity. The more sensitive a visitor is to noise, the more likely they are to have a higher motivation score for hearing natural sounds.

Neighborhood sound level. Because perception of the soundscape is influenced by more than just the physical measure of sound (Benfield et al., 2014), it is important to explore individual characteristics that effect soundscape judgments. Within the environmental noise literature, researchers have concluded that people in different communities perceive identical sounds to be either less annoying or more annoying based on their personal norms and attitudes (Marin et al., 2011; Schomer et al., 2013). Differing from previous research, this study is the first to explore the relationship between the sound level of individuals' neighborhood and their perception of park soundscapes.

Our findings suggest individuals' home sound environment contributes to visitors' perception of the pleasantness of the park's soundscape. Specifically, as neighborhood sound level increased, the rating of soundscape pleasantness decreased. Additionally, a large portion of our sampled population was from urban areas (population over 50,000). While the survey did not include questions about these variables, the observed trend could be the result of learned deafness, when humans and animals become accustomed to noise (Hatch & Fristrup, 2009; Fristrup, 2015). Individuals could be ignoring the sounds around them to block out unwanted sounds or noise. Whether learned deafness in response to irrelevant sounds transfers to learned deafness to relevant sounds is an important area of future research. For instance, might learned deafness influence the magnitude of restorative effects from natural sounds?

Another justification for the negative relationship between neighborhood noise level and pleasantness is that respondents living in noisier neighborhoods are accustomed to noise and uncomfortable with, or less appreciative of quiet, natural soundscapes. This could also hold true if those living in noisy areas are purposely masking unwanted noise with other sounds (e.g., from music, television, a white noise machine, or noise canceling headphones). A habituation to noise might make quieter soundscapes elicit uneasy feelings, thus rating the soundscape as less pleasant. This trend could also be a result of people living in urban settings reporting higher rates of noise induced hearing loss (Lewis, Gershon, & Neitzel, 2013). Many Americans are exposed to harmful levels of noise (Hammer et al., 2014) and in 2012 it was estimated that 24% of adults experienced hearing loss as a result of noise exposure (Carroll et al., 2017). Although it was not measured in this study, it is possible that respondents living in noisy urban areas experience higher rates of hearing loss or other disorders and were less likely to rate the soundscape as pleasant.

Planning and management implications. Management of natural soundscapes in protected areas is important for conserving wildlife, and for providing visitors with holistic benefits. Our findings demonstrate how various factors influence the perception of soundscape pleasantness. MUWO designates certain areas of the park as "quiet zones", and empirical evidence shows that this method is successful in quieting the park (Stack et al., 2011a). It is important for other parks, especially those close to urban centers, to adopt similar management techniques. While parks might be quieter than a busy downtown area, it's important to keep these protected places quiet, so that visitors have the opportunity benefit from the ecosystem services they provide (Ferraro, et al., 2020; Gidlöf-Gunnarsson & Öhrström, 2007).

National Park units across the United States are taking steps to implement policies that protect natural soundscapes. Findings from this study suggest that other agencies could develop plans to protect natural sounds and quiet, thus leading to a quieter protected area soundscape. In a study of perceived restoration experiences in urban parks, Payne (2008) found that visitors' perception of the soundscape plays a significant role in their restorative experience. Urban parks that can provide experiences that improve the wellbeing of urbanites should design spaces that reduce human sounds. This can be done by creating messaging and associated zones that influence visitors to keep quiet, avoid cell phone use, and mute music. Finally, this study highlights the importance of quiet natural places, such as urban parks. As the United States continues to urbanize, cities should prioritize the development and maintenance of urban parks for the wellbeing of its residents (Larson, Jennings, Cloutier, 2016)

Limitations and future research. Our study suggests that individual exposure to sound can impact perceptions of a protected area soundscape. Additionally, we found a negative relationship between noise sensitivity and the sound level associated with one's home zip code. It would be valuable to explicitly examine how noise sensitivity varies with typical noise exposure. Do people choose to live in rural or quieter areas because they are sensitive to noise? Understanding these relationships would also help researchers to better understand the connection between sound level and housing values. Farmer et al. (2013) found that neighborhoods with higher levels of bird diversity also had higher housing values. Perhaps those who are sensitive to noise are willing to pay more to live in a quieter area, thus gaining more opportunities for natural sound exposure. Future research is needed to understand individual perceptions of soundscapes.

Conclusion

This study utilized subjective measures of individuals' soundscape perceptions through variables such as noise interference, noise sensitivity, and motivations; as well as, objective measures such as neighborhood sound levels. These findings convey the notion that one's day-to-day exposure to sound impacts the person's perception of sound during a park visit. Schomer et al. (2013) emphasized the role of community context in soundscape perception, especially in terms of urban, suburban, and rural communities. For example, common urban sounds like emergency sirens and beeping horns might be considered normal for a resident living in a large city center, but very unfamiliar in a rural farm community. Ultimately, when visitors leave their home environments to visit parks, their perceptions of the park soundscape are shaped by the sound level of their community.

More than 145 million Americans (~44%) experience sound levels that exceed those recommended to protect public health (Hammer et al., 2014). Parks are important for providing natural soundscapes, especially for people living near urban centers where sound levels are the highest. We show that relationships with soundscapes can be complex and that the sound level experienced on a daily basis can influence one's perception of a park soundscape. We found that individuals from neighborhoods with higher background sound levels rated the MUWO soundscape as less pleasant. This could be a result of learned deafness and/or a comfort in urban sounds that coincide with living in areas with increased sound levels. Moreover, those who experienced increased interference with natural sounds found the soundscape to be less pleasant. Urban park planners can use evidence from this study to inform future research and management related to natural sounds and the ecosystem services or benefits they provide to human health and wellbeing.

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Table 1 (on next page)

Details on survey questions, response values and how they relate to understanding the visitor and sound perception.

Table 1. Details on survey questions, response values and how they relate to understanding the visitor and sound perception.

	Question	Value Range
Motivation	Please rate the importance of each of the following reasons for your visit to Muir Woods National Monument today.	1 (not at all important) 5 (extremely important)
Geographic location	What is your home zip code?	Enter zip code
Perceptions of the soundscape		
Pleasantness	Visitors hear a lot of sounds, including natural sounds and human-made sounds. Based on your experiences today, how would you rate your pleasantness of the soundscape?	1 (very unpleasant) 6 (very pleasant)
Noise sensitivity scale	1) I am sensitive to noise 2) I find it hard to relax in a place that’s noisy. 3) I get mad at people who make noise that keeps me from falling asleep or getting work done. 4) I get annoyed when my neighbors are noisy. I get used to most noises without much difficulty (reverse coded).	1 (strongly disagree) 6 (strongly agree)
Noise interference	Based on your experience today, how well were you able to hear natural sounds?	1 (almost always clearly without interference from human-made sound) 5 (almost always with interference from human-made sounds)

Table 2(on next page)

Reliability analysis and descriptive statistics from independent and dependent variables

1 Table 1. Reliability analysis and descriptive statistics from independent and dependent variables.

Variables	Mean (sd)
Motivation α = .859	
To enjoy the quiet sounds of nature	4.08 (1.01)
To get away from the noise back home	3.60 (1.30)
Enjoying the peace and quiet	3.84 (1.08)
Hearing sounds of nature	3.84 (1.08)
Noise sensitivity scale α = .808	
I am sensitive to noise	3.76 (1.59)
I find it hard to relax in a place that's noisy.	4.48 (1.35)
I get mad at people who make noise that keeps me from falling asleep or getting work done.	4.41 (1.45)
I get annoyed when my neighbors are noisy.	4.39 (1.28)
I get used to most noises without much difficulty (reverse coded).	3.27 (1.27)
Single item measures	
Pleasantness	5.24 (1.00)
Noise Interference	2.37 (1.07)

2
3

Table 3(on next page)

Model selection for pleasantness

Table 3. Model selection for pleasantness

Model equation[1]
Pleasantness ~ Neighborhood sound level
Pleasantness ~ Neighborhood sound level + noise sensitivity
Pleasantness ~ Neighborhood sound level + noise sensitivity + noise interference
Pleasantness ~ Neighborhood sound level + noise sensitivity + noise interference + sound motivation
Pleasantness ~ Neighborhood sound level + noise sensitivity + noise interference + sound motivation + quiet v. control
Pleasantness ~ Neighborhood sound level + noise sensitivity + noise interference + sound motivation + hourly L50
Pleasantness ~ Neighborhood sound level + noise sensitivity + noise interference + visitor count

1

Table 4(on next page)

Final linear model for pleasantness (transformed) Pleasantness ~ Neighborhood sound level + noise sensitivity + noise interference + sound motivation

Table 4. Final linear model for pleasantness (transformed)

Pleasantness ~ Neighborhood sound level + noise sensitivity + noise interference + sound motivation

Fixed Effects	Estimate	SE	t	P
Intercept	112.89	12.72	8.88	<0.001
Neighborhood sound level	-0.50	0.22	-2.30	0.022
Noise sensitivity	-3.55	1.05	-3.36	<0.001
Noise interference	-9.54	1.02	-9.37	<0.001
Sound motivation	2.37	1.08	2.19	0.030

Table 5(on next page)

Post hoc linear model: Noise sensitivity ~ Neighborhood sound level + noise interference + sound motivation + hourly L50 + visitor count + quiet v. control.

Table 5 Post hoc linear model: Noise sensitivity ~ Neighborhood sound level + noise interference + sound motivation + hourly L50 + visitor count + quiet v. control

Coefficients	Estimate	SE	t	P
Intercept	6.12	2.22	2.74	<0.001
Neighborhood sound level	-0.02	0.01	-2.07	0.04
Noise interference	0.07	0.05	1.38	0.17
Sound motivation	0.13	0.05	2.52	0.01
Hourly L50	-0.04	0.06	-0.70	0.48
Visitor count	-0.00	0.00	-0.95	0.34
Quiet v. control	-0.08	0.12	-0.76	0.45

R^2=0.026

Table 6(on next page)

Post hoc linear model: Noise Interference ~ Neighborhood sound level + noise sensitivity + sound motivation + hourly L50 + visitor count + quiet v. control.

Table 6 Post hoc linear model: Noise Interference ~ Neighborhood sound level + noise sensitivity + sound motivation + hourly L50 + visitor count + quiet v. control

Coefficients	Estimate	SE	t	P
Intercept	-1.87	2.21	-0.84	0.40
Neighborhood sound level	0.01	0.01	0.84	0.40
Noise sensitivity	0.07	0.05	1.37	0.16
Sound motivation	-0.10	0.05	-1.89	0.05
Hourly L50	0.08	0.05	1.42	0.15
Visitor count	0.00	0.00	3.74	0.65
Quiet v. control	0.05	0.12	0.46	<0.001

R^2=0.096

Figure 1

Expected daytime sound level and location of visitors' home zip codes.

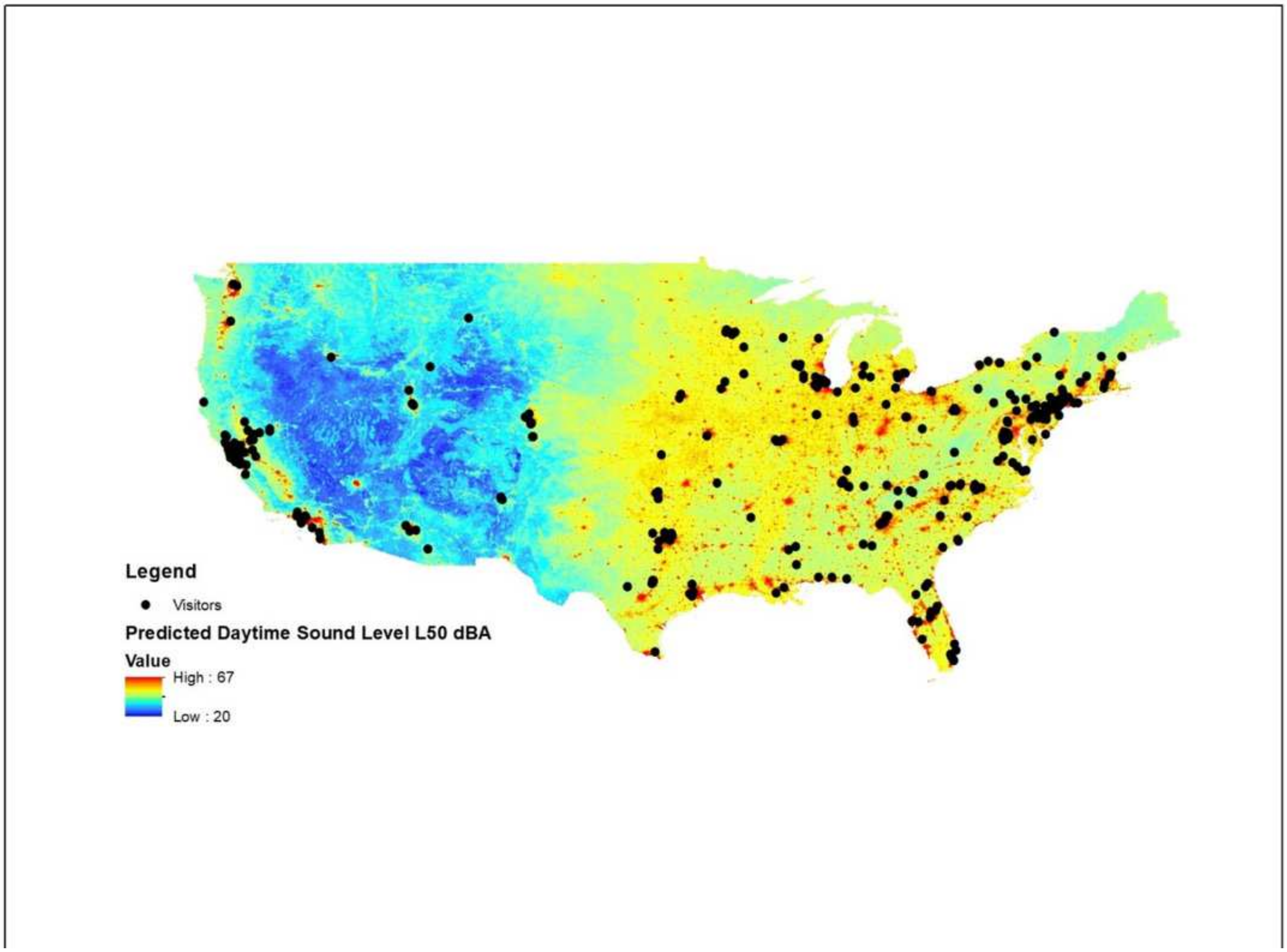


Figure 2

Distribution of visitors’ neighborhood sound levels

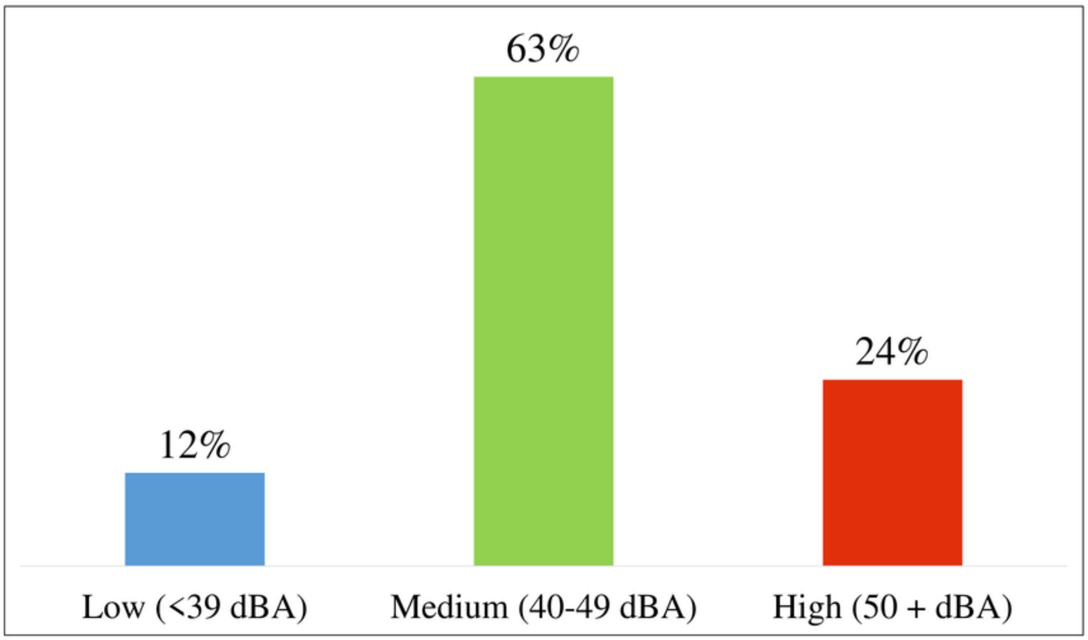


Figure 3

Distribution of visitors by rural and urban neighborhoods

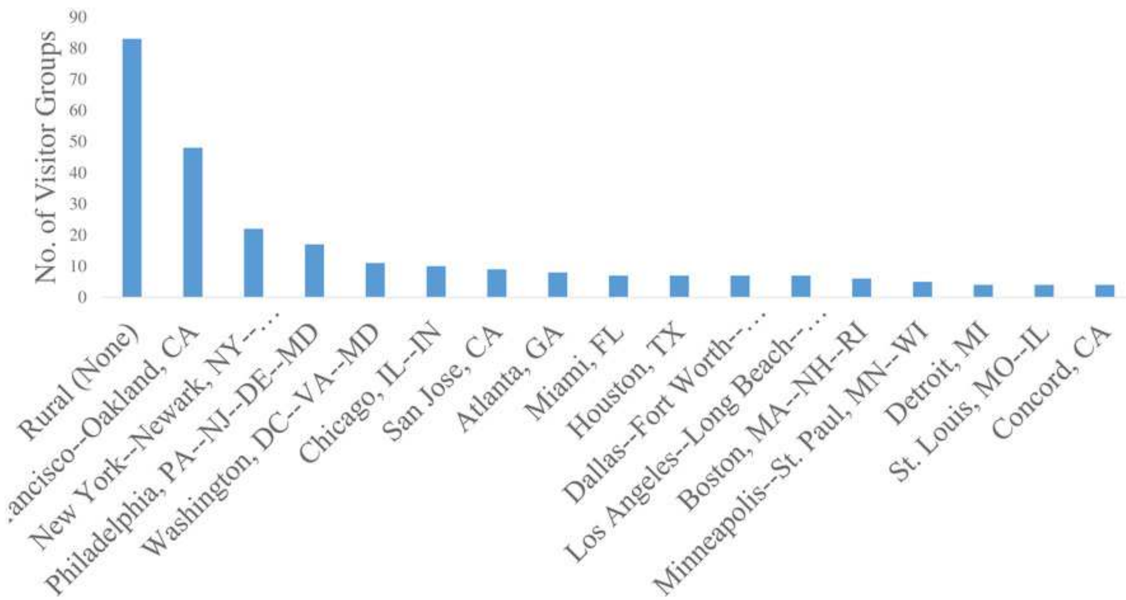


Figure 4

Marginal effects using the final model (Pleasantness ~ Neighborhood sound level + noise sensitivity + noise interference + sound motivation).

(a)Marginal effect of noise sensitivity on pleasantness; (b) Marginal effect of noise interference on pleasantness; (c) Marginal effect of neighborhood sound level on pleasantness; (d) Marginal effect of sound motivation on pleasantness.

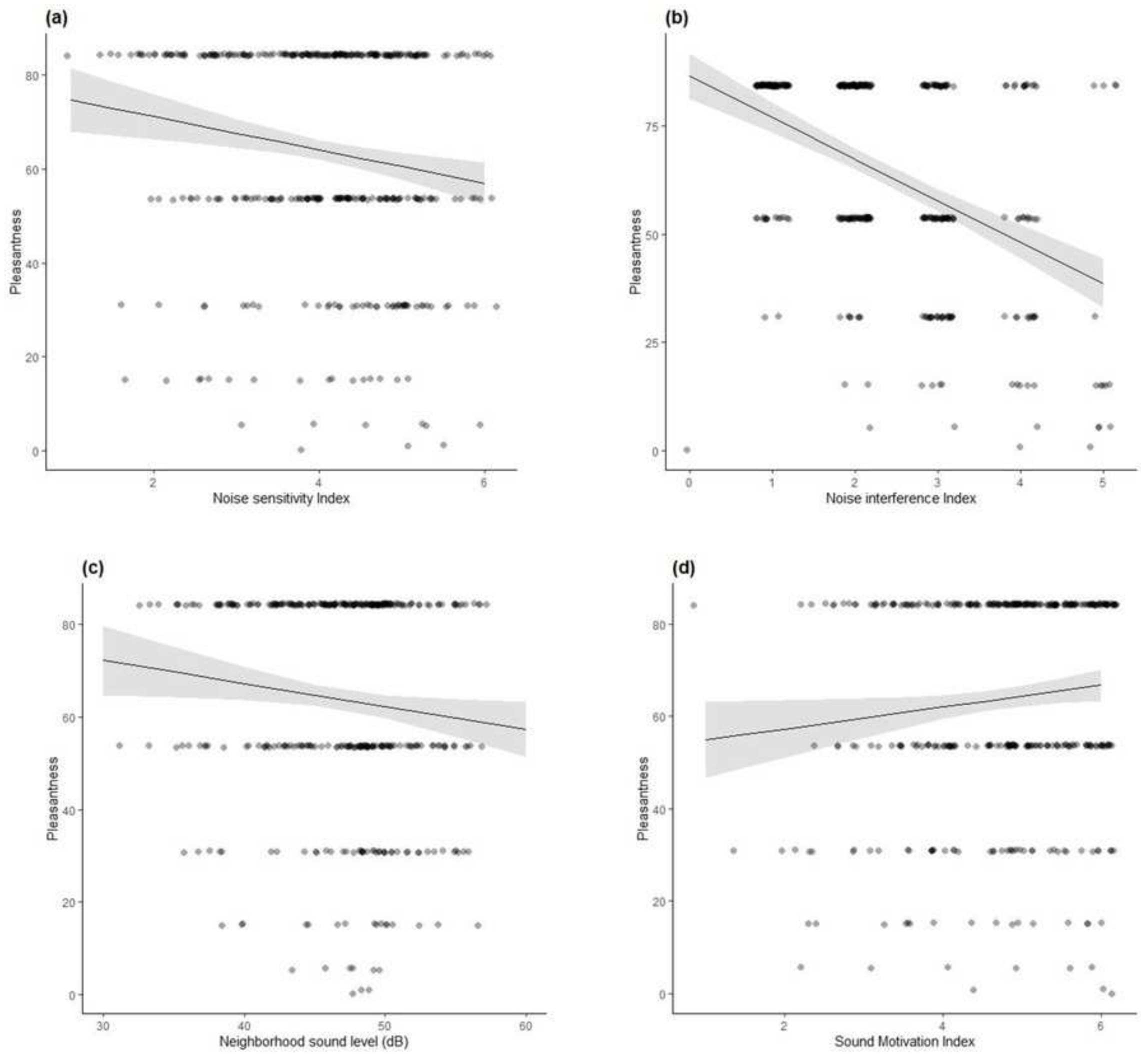
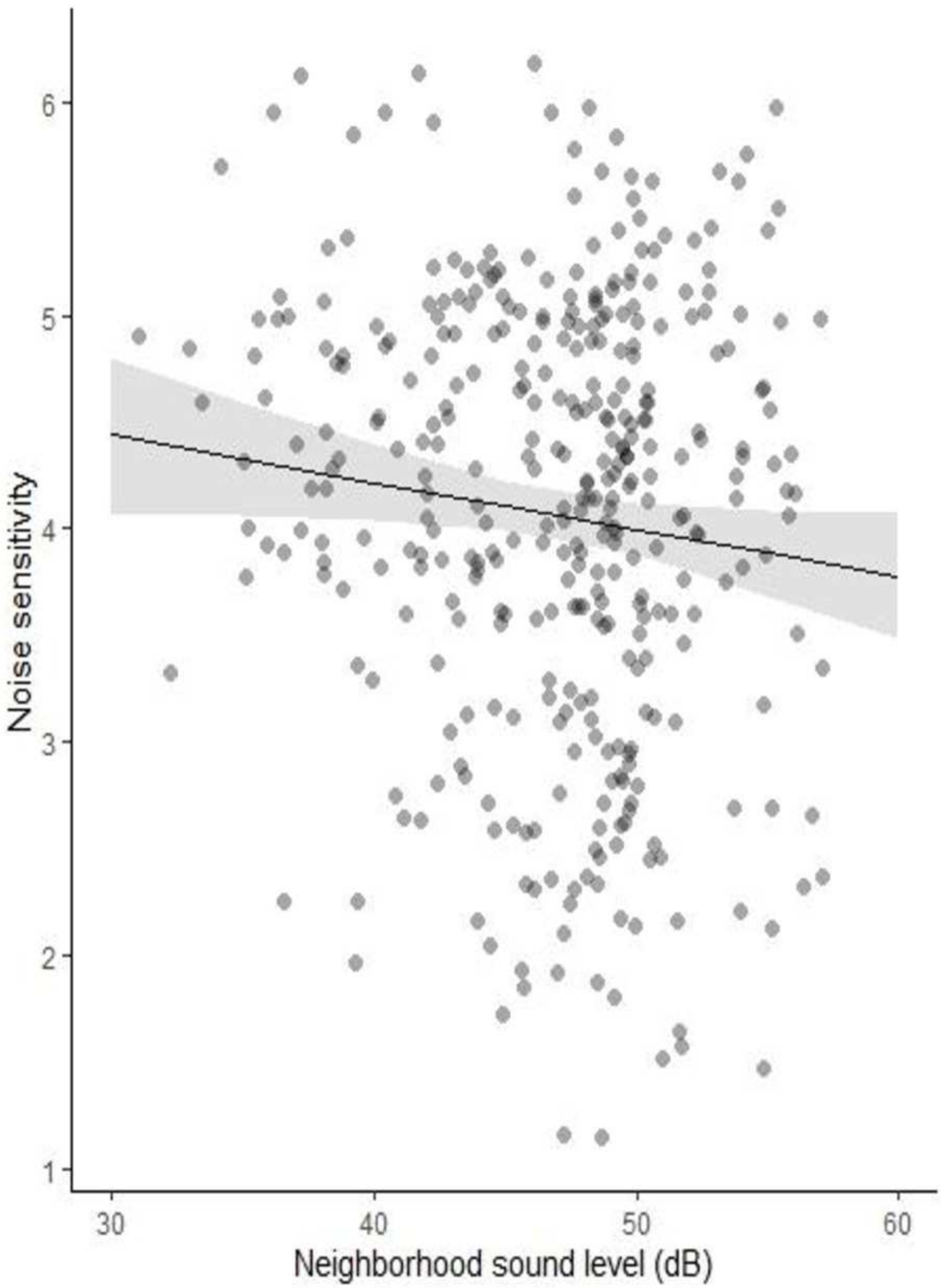

(a)
Pleasantness
Noise sensitivity Index
(b)
Pleasantness
Noise interference Index
(c)
Pleasantness
Neighborhood sound level (dB)
(d)
Pleasantness
Sound Motivation Index

Figure 5

Marginal effects of noise sensitivity and neighborhood sound level

Marginal effects of noise sensitivity and neighborhood sound level


Noise sensitivity
1
2
3
4
5
6
30
40
50
60
Neighborhood sound level (dB)