THE INFLUENCE OF ENVIRONMENTAL SOUNDS ON COGNITION AND MOOD

by

Huda Ahmed

Department of Psychology

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Advisor: Dr. Stephen Van Hedger

Reader: Dr. Irene Cheung

The thesis by:

Huda Ahmed

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Chair of Department

Abstract

Exposure to nature has evidently been shown to benefit affective states and improve cognitive performance. Due to the predominant focus on the influence of immersive environments on restoration in prior research, the current study aimed to examine the extent to which nature-related benefits are linked to perceptual richness. The study consisted of 204 participants, recruited from Amazon Mechanical Turk. Participants were randomly assigned to listen to either unaltered nature sounds, unaltered urban sounds, degraded nature sounds, or degraded urban sounds. Participants completed the Auditory N-Back task, self-reported fatigue levels, and provided mood ratings prior to and after listening to the assigned sounds. The Perceived Restorativeness Scale and Mental Bandwidth Scale were completed towards the end of the study to measure the extent to which participants found the sounds to be restorative. The results of the study indicate that nature sounds improve mood (increasing happiness and calmness and decreasing anxiety) regardless of sound quality. Listening to unaltered nature sounds were found to increase cognitive performance, whereas unaltered urban sounds decreased performance. Exposure to degraded sounds, in contrast, led to a weak increase in performance for both nature and urban sounds, suggesting that perceptually rich nature sounds may be required to observe a significant improvement in cognitive performance. The findings of the study demonstrate that although both unaltered nature sounds and degraded nature sounds result in affective restoration, performance-based cognitive restoration may require exposure to perceptually rich and high quality sounds. Implications of the findings and future directions for research are discussed.

Keywords: Nature, Restoration, Cognition, Affect

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Introduction

The psychological importance of interacting with nature has not gone unnoticed, as evidenced by the way individuals seek out natural environments for the many restorative qualities they possess. Natural environments have various perceptual qualities which allow individuals to immerse themselves in their surroundings after experiencing psychological or physiological stress, enabling mental resources to rest and replenish, and thereby improving cognition and affect (e.g., Kaplan, 1995; Ulrich, 1981). It is presently unclear, however, whether these nature-based restorative effects are robust to variations in the perceptual quality of the experience (e.g., listening to birdsong while immersed in the outdoors versus listening to birdsong on low-quality computer speakers). Determining the extent to which lower-quality nature sounds may elicit restorative experiences is important for understanding the mechanisms through which nature might improve psychological well-being. Thus, the present study examines whether degrading the perceptual experiences of natural environments attenuates cognitive and affective benefits.

Contact with nature has been consistently shown to benefit mood and affective states (McMahan & Estes, 2015; Neill et al., 2019; Brooks, 2017). Prior research has established a link between interactions with natural environments and an increase in positive affect, even when these interactions occur for a short period of time (McMahan & Estes, 2015). Notably, individuals can experience these improvements in mood within five minutes of interacting with nature, indicating once again that even brief exposures to nature can be beneficial (Neill et al., 2019). Nature has been found to increase subjective well-being, allowing individuals to experience a higher level of happiness and enjoyment (McMahan & Estes, 2015). Schertz et al. (2018) found that exposure to the greenery of an environment not only shows increases in happiness, but also increases in positive thinking regarding one's relationships and surroundings. In a study by Neill et al. (2019), individuals experienced an increase in self-transcendent emotions, such as awe and gratitude, as well as hedonic emotions, including pleasure and comfort, after spending time in a natural setting. In addition to an increase in positive emotions, contact with nature has the ability to decrease negative emotions, including behaviours related to depression, such as rumination (McMahan & Estes, 2015; Berman et al., 2012). Nature-related benefits on mood have also been found to be consistent through different seasons, including winter seasons when a decrease in well-being and an increase in physical discomfort from the cold weather are likely to be experienced (Brooks et al., 2017).

Along with affective state, the benefits of engaging with nature have been shown to extend to cognitive functioning, including improved directed attention, working memory, and even cognitive development (Tennessen & Cimprich, 1995; Berto, 2005; Berman et al., 2008, Dadvand et al., 2015). For instance, a study by Tennessen and Cimprich (1995) found that individuals who had interacted with nature had improved directed attention compared to those who had interacted with a built environment. This suggests that nature has the ability to restore and maintain attention when one experiences fatigue or an increased demand in directed attention (Tennessen & Cimprich, 1995). Prior research has also shown improvements in working memory and attention after taking a walk in nature, or simply viewing photographs of nature (Berman et al., 2008). Similarly, a study by Van Hedger et al. (2019a) indicated that briefly listening to nature sounds in the lab resulted in improvements in cognitive functioning, including directed attention. In contrast to this, urban environments have shown to make no significant impact on cognitive performance when examining directed attention (Van Hedger et al., 2019a; Berman et al., 2008). Therefore, the cognitive benefits of interacting with nature involve comparing the relative performance changes of nature exposure to the relative performance changes of urban exposure, and are often quantified statistically as an interaction term.

Nature-related benefits on cognitive functioning and mood have been explained by two prominent theories: Attention Restoration Theory (ART; Kaplan, 1995) and Stress Reduction Theory (SRT; Ulrich, 1991). ART posits that in order to recover from mental fatigue, it is vital for depleted cognitive resources to replenish and undergo restoration (Kaplan, 1995). There are four established components of ART which indicate the restorativeness of an environment: (1) being away, (2) fascination, (3) extent, and (4) compatibility. 'Being away' involves resting and freeing mental resources from activities which demand directed attention (Kaplan, 1995). Natural environments incorporate this component as they allow for easy and accessible opportunities of 'being away'- such as parks, lakes, and forests - and therefore provide directed attention a chance to rest. However, 'being away' does not necessarily involve physical travel, as restorative environments allow one to 'be away' psychologically. 'Fascination' refers to the ability to focus one's attention without extensive effort or feeling drained, and soft fascination within natural environments can result in moments of reflection (Kaplan, 1995). Natural environments involve many features, including clouds or trees, which can induce feelings of soft fascination and effortlessly capture attention. A restorative environment must also involve 'extent', which refers to a rich, coherent, and somewhat familiar environment that can keep an individual engaged and immersed (Kaplan, 1995). This allows individuals to feel comfortable and secure within the environment, as it is unlikely to contain any unexpected qualities. The final component of ART includes 'compatibility', which proposes that the environment must be in line with the individual's goals, purposes, and preferences (Kaplan, 1995). A natural environment which is compatible will allow the individual to carry out activities without difficulty and will result in feelings of comfort and enjoyment.

In comparison to natural environments, urban or manmade settings often represent an individual's 'status-quo' environment and thus do not afford the same opportunities to 'get away' and to rest one's mental resources. While natural environments allow for individuals to experience 'soft fascination', urban environments involve 'hard fascination', where there is an increased demand for attention (Kaplan, 1995). Urban settings demand attention due to their highly stimulating environment and thus, do not always offer a chance of reflection. Furthermore, urban environments may lack 'extent' due to the way they consist of various stimuli which are often unfamiliar or unexpected. These stimuli may result in a 'collection of impressions', where one is unable to thoroughly think about or immerse themselves in their surroundings (Kaplan, 1995). Similarly, whereas natural environments provide individuals with compatible environments, urban settings often lack compatibility as a result of the distractions that are incorporated within them. Hence, although natural environments allow for depleted cognitive resources to replenish, urban environments contain various stimulating factors and demand an increase in directed attention, which can then impede restoration (Berman et al., 2008).

The restorative benefits of nature can also be understood by Stress Reduction Theory (SRT). SRT is closely based on the evolution of human beings in natural environments, as opposed to urban environments. As a result of adaptive responses, engaging with nature has shown to decrease levels of stress along with an increase in positive affect, ostensibly because humans have an evolutionary affinity for biodiverse, natural environments (Ulrich, 1991). A study by Ulrich (1981) found that exposure to nature, such as water and vegetation, positively influenced psychological states, including attentiveness and positive affect. Furthermore, contact with nature was most beneficial to individuals when they were experiencing high arousal and anxiety, such that levels of arousal were found to be reduced (Ulrich, 1981). However, individuals experiencing no stress were also found to benefit from exposure to nature (Ulrich, 1981). On the other hand, urban environments are likely to increase the levels of arousal one may experience, and as a result, may also increase levels of anxiety (Ulrich 1981). SRT explains the various nature-related benefits on affective state, specifically the ways in which stress decreases and positive affect increases. Accordingly, SRT is also compatible with cognitive benefits of nature; however, it would suggest that these cognitive benefits might be mediated through reduced stress and increased positive affect (Yang et al., 2013).

Intriguingly, nature-related benefits do not necessarily have to involve being physically immersed within the environment. The benefits of nature on cognitive functioning and affective state have been found in various studies which focus on videos of nature, photographs of natures, nature sounds, and virtual nature settings (Ulrich, 1991; Berto, 2005; Van Hedger et al., 2019a; Valtchanov et al., 2010). In a study conducted by Ulrich (1991), emotional state and attention were found to be improved when participants watched videotapes of nature. The settings in the videotapes involved natural vegetation, water, heavy traffic, and pedestrians. Although the benefits were seen when viewing the videotapes of natural settings, exposure to the videotapes of urban settings did not reap the same benefits (Ulrich, 1991). Furthermore, viewing photographs of natural settings have been discovered to have restorative benefits and reduce attentional fatigue (Berto, 2005). In contrast to this, no significant improvements in restoring attentional capacity have been found when viewing photographs of non-restorative environments, such as urban settings (Berto, 2005).

Similarly, nature-related benefits are also associated with natural sounds, such as sounds of rainfall, birdsong, insects, and wind (Van Hedger et al., 2019a). Brief exposures to natural sounds have been found to result in improvements in cognitive functioning, including attention, when examining performance on cognitively demanding tasks (Van Hedger et al., 2019a). In addition to this, virtual computer-generated nature settings have indicated the ability to have restorative effects (Valtchanov et al., 2010). Individuals exposed to a virtual reality nature setting were shown to have an increase in levels of positive affect, along with a decrease in levels of stress, within 10 minutes of immersion (Valtchanov et al., 2010). Therefore, it is evident that the benefits of nature can be extended to non-physical experiences with natural settings, and nature-related benefits can be examined using various tools such as photographs, videotapes, sounds, and virtual reality.

The benefits that are observed in non-physical experiences with natural environments can be seen to be consistent with the components of ART. Although it is believed that physical immersion and physically interacting with nature may provide the strongest restorative effects, non-physical interactions with nature have also been established to exhibit the same effects. This is particularly due to experiencing feelings of 'being away', one of the crucial components of both ART and restorative environments as a whole. As mentioned previously, 'being away' involves the ability to immerse oneself in a restorative environment. When one experiences 'being away' from their accustomed environment, they are provided with the opportunity to clear away their thoughts and rest their fatigued mental resources. However, this does not specifically refer to a physical environment, and instead refers to a conceptual or psychological feeling of 'being away' (Kaplan, 1995). Therefore, in order for an environment to be restorative, it is required to be sufficiently rich and immersive, which will then lead to experiencing feelings of 'being away'.

According to this framework, it can be argued that the perceptual richness (i.e., the 'quality') of the experience involving interaction with nature plays an important role. An environment which is perceptually rich will allow individuals to experience a sense of 'being away' and 'fascination', and therefore result in an increased immersive experience (Kaplan, 1995). In order for an experience to be perceptually rich and immersive, it must contain stimuli which are coherent and of high quality. In contrast to this, if an experience with nature involves the degradation of these perceptual experiences (e.g., viewing black-and-white images), it is possible that one may not experience high levels of 'fascination', 'extent', or 'being away' even if the environment is still clearly identifiable as natural. However, a study conducted by Van Hedger et al (2019b) has found that individuals continue to show strong preferences for nature (versus urban) sounds, even when these sounds are heavily degraded to sound artificial, *as long as they can explicitly recognize the sounds as originating from nature*. In contrast, sounds that cannot be explicitly identified as originating from nature are not preferred over urban sounds, even if they originated from natural environments. These findings indicate that the perceptual quality of the experience of nature might not matter in terms of restoration, as long as the environment can still be understood and categorized as originating from nature. However, Van Hedger et al. (2019b) focused exclusively on aesthetic preferences, and did not explicitly test how degraded sounds might influence the restorative benefits of nature. Thus, it is unclear whether listening to degraded nature sounds would improve cognitive performance or affect.

The present study seeks to examine the extent to which nature-related benefits on restoration are associated with the perceptual richness of the intervention. Due to the presumed importance of immersive environments and their influence on restoration, past research has mainly focused on rich environments or high-quality media files to examine nature's influence on cognitive performance. However, perceptual quality is an important aspect of restoration to examine as it has the ability to offer insight into how essential it is for an environment to be highly immersive in order for one to experience cognitive benefits. To address this, the present study will consist of four conditions, which will involve participants listening to one of four different sound types: (1) unaltered (rich) nature sounds, (2) degraded nature sounds, (3) unaltered (rich) urban sounds, or (4) degraded urban sounds. This study will measure working memory and affect before and after listening to these sounds, and it will also ask participants to rate the perceived restorativeness of these sounds. It is hypothesized that listening to nature sounds, in contrast to urban sounds, will improve working memory performance when comparing pre-test performance to post-test performance. However, this effect of nature is expected to interact with perceptual quality, such that listening to degraded nature sounds will result in overall attenuated gains in working memory performance. This would be consistent with ART, as degraded nature sounds are likely to be less fascinating, less compatible, and may not invoke a sense of 'being away' (Kaplan, 1995). Additionally, the degradation of nature sounds is not predicted to have a large influence on affective state. Improvements in affective state are expected to be found as long as participants recognize the origin of the sounds as nature (cf. Van Hedger et al., 2019b). These predictions are in line with SRT and the way in which nature positively influences psychological states (Ulrich, 1981). Overall, participants who listen to unaltered nature sounds are hypothesized to show a higher level of improvement in both working memory performance and affect compared to those who listen to degraded nature sounds.

However, the relative difference between unaltered and degraded sounds is expected to be higher for working memory compared to affect.

Method

Participants

A total of 250 participants were recruited from Amazon Mechanical Turk (MTurk), an online platform for recruiting research participants. CloudResearch (Litman et al., 2017) was used in order to establish a more stringent criteria when recruiting participants through MTurk. Participants were eligible to enroll in the study if they successfully passed internal attention checks conducted by CloudResearch and if they received a 90% prior approval rating from prior MTurk tasks. Participants were based in the United States, and were provided with $7.50 USD as compensation for their participation in the study.

243 participant data files were successfully saved to the server. From this total, 14 participants were removed for failing the auditory attention check and five additional participants were removed due to failing the written attention checks. Participants were also required to meet a minimum of 67% response rate in the Auditory N-Back task as the instructions clearly stated that it was necessary to respond to each letter. As a result of failing to pass this threshold, 10 participants were removed. Furthermore, nine participants were removed due to additional issues that were raised in the questionnaire free response. Seven of these participants reported use of a hearing aid, one participant identified as having ASD, and one participant copied and pasted the study title, which suggested task noncompliance.

The final sample of 204 participants consisted of 115 men, 89 women, and one individual who identified as non-binary. Participants were between the ages of 21 and 71 (M = 40.37, SD =

11.71). Of the 204 included participants, 45 participants listened to degraded nature sounds, 57 listened to unaltered nature sounds, 49 listened to degraded urban sounds, and 53 listened to unaltered urban sounds.

Materials

The study was programmed in jsPsych 6 (de Leeuw, 2015), and participants were able to access the study from their own computers.

Headphone Assessment. Participants were presented with different tones as described by Woods et al. (2017), and were asked to make judgments about the perceived loudness of the tones. This assessment is designed to be easy for those using headphones, and difficult for those listening to the tones without the use of headphones. The use of headphones was encouraged, but not required, and therefore was not used as an exclusion criteria. A total of 164 participants passed the headphone assessment.

Intervention Stimuli. The study utilized the natural and urban stimuli from Van Hedger et al. (2019a), which displayed effects of cognitive restoration after being exposed to nature sounds compared to urban sounds. A total of 40 nature sounds and 40 urban sounds were used, and each of these sounds were 14 seconds in duration. Each category of sounds contained a diverse range of sounds. Nature sounds included birdsong, insects, running water (rain, river, waves), and wind. Urban sounds included traffic, machinery noise, background conversation (e.g., from a coffee shop or restaurant), and construction. The degraded stimuli were derived from the files of unaltered nature and unaltered urban sounds. The degraded sounds were bandpass filtered between 400 and 2500 Hz, using a tenth-order Butterworth filter. This was not expected to substantially impact the categorization of sounds as natural or urban (cf. Van Hedger et al., 2019b). However, this specific manipulation was expected to result in perceptually "thinner" sounding sounds, which was hypothesized to influence participants' liking of the sound, as well as their judgement of the sound quality.

Auditory N-Back Task. The Auditory N-Back (ANB) consisted of spoken letters created from a text-to-speech synthesizer (female voice) using the 'TTSAutomate' program. Five blocks of letters were presented in the same order each time, including one block of a one-back, two blocks of a two-back, and two blocks of a three-back. Each block contained 30+*n* spoken letters (inter-letter interval of 2500 ms) which were composed of 10 target letters and 20 non-target letters, randomly determined for each block. Participants were instructed to respond to each letter by pressing one designated key if the letter was a target (i.e., if the current letter was the same as the one spoken n position(s) previously), and a second designated key if the letter was a non-target (i.e., if the current letter was different than the one spoken n position(s) previously).

Perceived Restorativeness Scale. The Perceived Restorativeness Scale (PRS; Norling et al., 2008) contains nine items which aim to assess the perceived restorativeness of the nature and urban sounds in the present study. The PRS contains three subcomponents, including 'being away', 'extent', and 'fascination', with each subcomponent consisting of three items. Participants rated each item on a five-point Likert scale, ranging from one (*very slightly or not at all*) to five (*extremely*). A recent study (Brancato et al., 2022) using this version of the PRS found high scale reliability for the three subcomponents ('being away': $\alpha = .94$, 'extent': $\alpha = .94$, 'fascination': $\alpha = .92$).

Mental Bandwidth Scale. The Mental Bandwidth Scale (MBS; Basu et al., 2019) contains seven items which assess the extent to which an activity expends mental bandwidth. In this study, the activity involved listening to either nature or urban sounds. The MBS involves three subcomponents: 'self-awareness' (two items), 'daydreaming' (three items), and 'planning' (three items). All items were rated on a five-point Likert scale, ranging from one (*very slightly or not at all*) to five (*extremely*). Basu et al. (2019) found good reliability of each subcomponent of the MBS (‘self-awareness’: α = .72, ‘daydreaming’: α = .81, ‘planning’: α = .83).

Visual Analog Scale. The Visual Analog Scale (VAS; Brancato et al., 2022) was completed by participants to rate how they were currently feeling on five terms: happy, sad, lonely, calm, and anxious. Each item was rated on a 100-point slider scale based on the level of the particular term participants were feeling in the present moment. Brancato et al. (2022) reported good test-retest reliability for the VAS (happy: r = .85, sad: r = .73, calm: r = .75, anxious: r = .73, lonely: r = .79).

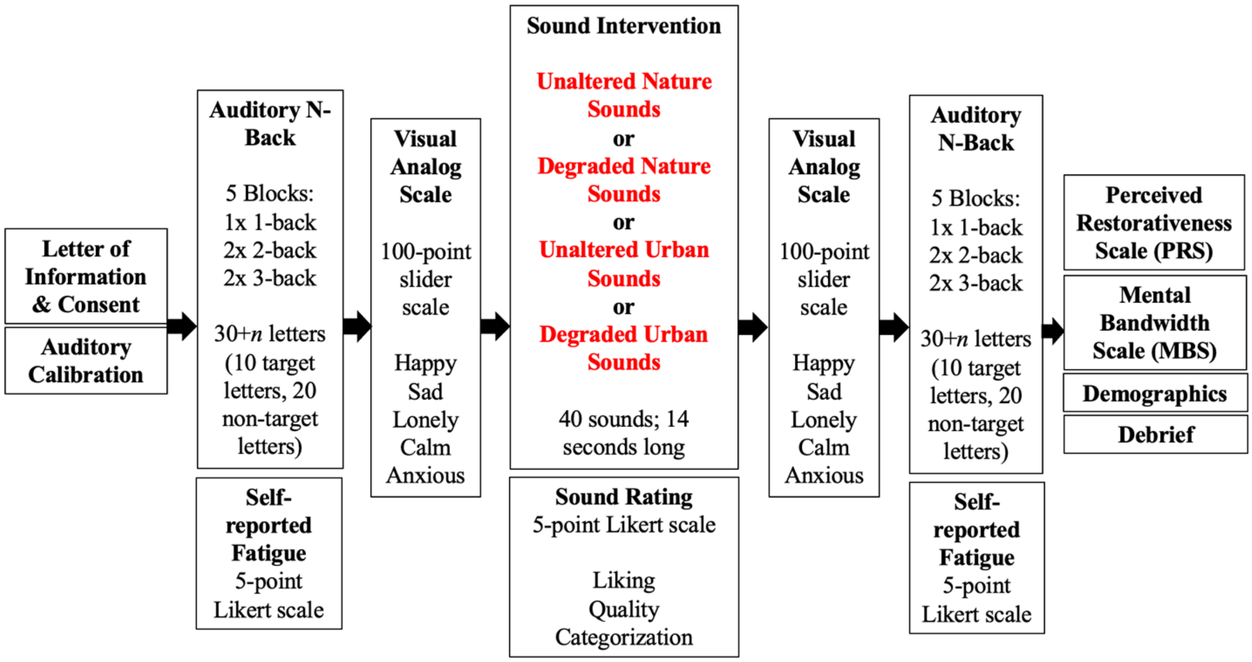
Demographic Questionnaire. Participants were asked to report their age, gender, and highest level of education. The questionnaire also asked participants to self-report use of hearing aid or any health concerns which may have influenced their performance in the study. Additionally, participants were provided with a space to attempt to guess the purpose of the study.

Procedure

Figure 1 provides an overview of the experimental procedure. Participants were first presented with the letter of information, followed by participants being directed to a screen to provide informed consent. Due to the online nature of the study, consent was obtained by clicking a box that read either ‘yes’ or ‘no’, in response to the statement ‘I agree to participate in the study’.

After participants provided consent to participate, they were asked to complete an auditory calibration. The auditory calibration assessed whether participants were using

Figure 1. Experimental design.



headphones via six trials in which participants judged which of three presented tones was the loudest (Wood et al., 2017), and provided participants an opportunity to adjust their computer's volume to a comfortable listening level. Participants were then asked to complete the ANB Task, where they first completed a one-back task which served as a practice run. Afterwards, participants completed a two-back task and a three-back task, with breaks provided every 30 letters. Immediately after the completion of the ANB Task, participants were asked to self-report fatigue ("How fatigued are you feeling in the present moment?") on a five-point Likert scale, ranging from one (*not at all*) to five (*extremely*). Next, participants were presented with an auditory attention check. This involved a simple prompt that asked participants to click on one of four labeled buttons that appeared on the screen. After completing the auditory attention check, participants were presented with the VAS to provide ratings of their mood.

Depending on condition assignment, which was randomly determined upon loading the experiment, participants then listened to one of four sound types: unaltered nature sounds, unaltered urban sounds, degraded nature sounds, or degraded urban sounds. After listening to each sound, participants were asked to provide ratings based on three prompts. The first prompt assessed the participant's liking of the sound ("How much did you like the recording you just heard?"), with responses being made on a five-point Likert scale ranging from one (*strongly dislike*) to five (*strongly like*). The second prompt assessed the participant's judgement of the sound quality ("Please rate the sound quality of the recording you just heard."), with responses being made on a five-point Likert scale ranging from one (*low quality*) to five (*high quality*). The third prompt assessed the participant's identification of the sound as natural or urban ("To what extent did the recording convey an urban (versus natural) setting?"), with responses being made on a five-point Likert scale ranging from one (*very urban*) to five (*very natural*). Following the completion of the sound rating task, which consisted of 40 total sounds, participants once again completed the VAS, the ANB Task, and the self-reported fatigue measure in this order.

Next, participants completed the PRS and MBS. Written attention checks were embedded into both the PRS and MBS, where participants were asked to "select 'moderately' for data quality purposes" in the PRS, and "select 'extremely' for data quality purposes" in the MBS. Following the PRS and MBS, participants were asked to complete a demographic questionnaire to provide their age, gender, and highest level of education. Participants were also asked to guess the purpose of the study. Lastly, participants were compensated for their participation and were presented with a debriefing letter which described the study and explained the reasoning behind the use of mild deception.

Data Analysis

The VAS, ANB, and Self-Reported Fatigue analyses were administered both before and after the sound intervention, and thus used a 2 (Time: Pre, Post) x 2 (Environment: Nature, Urban) x 2 (Quality: Unaltered, Degraded) mixed ANOVA. Time was a within-participant factor, whereas Environment and Quality were between-participant factors. Performance on the two-back and three-back, as well as each term on the VAS, were considered in separate ANOVAs. The ratings of the intervention sounds (in terms of liking, sound quality, and naturalness) and the restorativeness scales (PRS and MBS) used a 2 (Environment: Nature, Urban) x 2 (Quality: Unaltered, Degraded) between-participant ANOVA. Given the number of performed analyses, all *p*-values were corrected based on the Benjamini-Hochberg procedure (Benjamini & Hochberg, 1995) for controlling the False Discovery Rate (FDR). As such, all analyses report *q*-values.

Results

Auditory N-Back Task

The results of the two-back task showed a significant main effect for Time, $F(1, 200) = 17.71$, $q < .001$, $\eta^2 p = 0.08$. Overall, participants showed an increase in performance in the second administration of the task relative to the first administration. No interactions were found between Time and Environment, between Time and Quality, or between Time, Environment, and Quality. The results of the three-back task indicated that there was a marginal Time-by-Environment interaction, $F(1, 200) = 4.71$, $q = .085$, $\eta^2 p = 0.02$. Participants who listened to nature sounds showed an increase in post-test performance ($M = 1.40$, $SD = 0.75$) in comparison to pre-test performance ($M = 1.26$, $SD = 0.77$). Participants who listened to urban sounds were found to show a nominal decrease in post-test performance ($M = 1.30$, $SD = 0.81$), compared to their pre-test performance ($M = 1.35$, $SD = 0.77$). Overall, nature sounds resulted in an improvement in performance in contrast to urban sounds. However, this relative benefit of nature sounds appeared to be entirely dependent on Quality, as evidenced by the three-way interaction of Time, Environment, and Quality, $F(1, 200) = 4.42$, $q = .087$, $\eta^2 p = 0.02$. This three-way interaction is characterized by pronounced improvements in performance following unaltered nature sounds and pronounced deficits in performance following unaltered urban sounds (Figure 2A). In contrast, degraded nature and urban sounds showed comparable slopes, which were both mildly positive (Figure 2B).

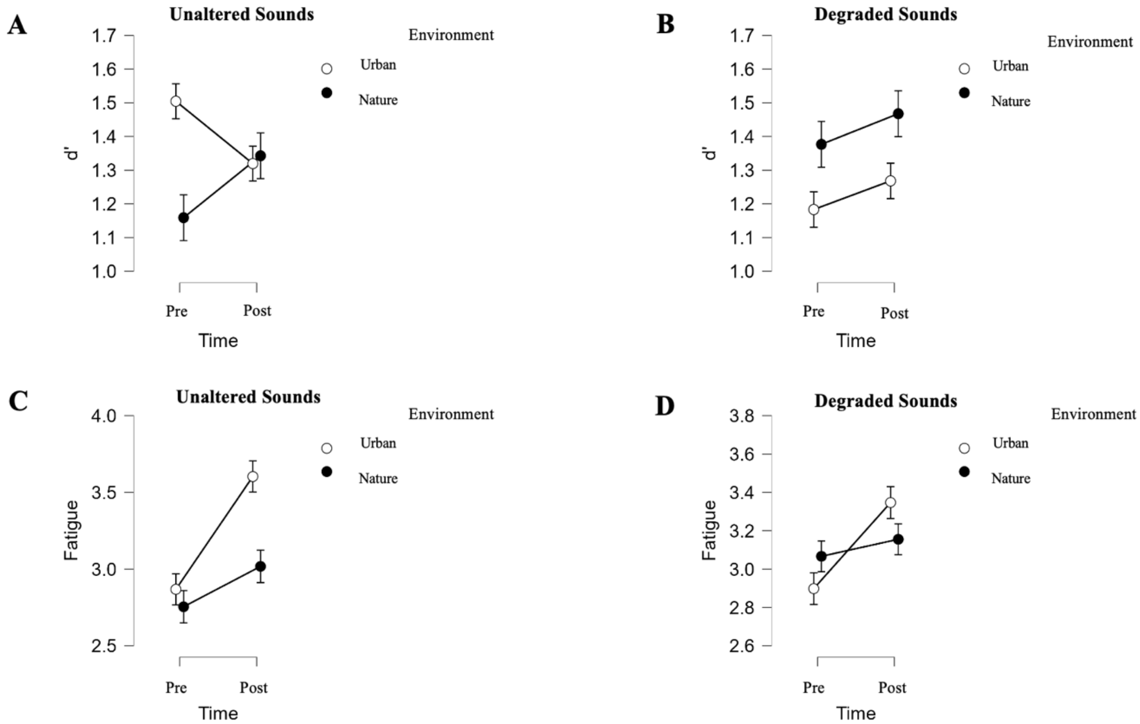
Self-reported Fatigue

The results showed a significant main effect of Time, $F(1, 200) = 32.28$, $q < .001$, $\eta^2 p = 0.14$, with fatigue ratings increasing after the second administration of the ANB. The results also indicated an interaction between Time and Environment, $F(1, 200) = 9.48$, $q = .006$, $\eta^2 p = 0.05$, with fatigue ratings showing a significantly steeper increase in the urban sound conditions compared to the nature sound conditions (Figure 2C-D). No other term was significant in the model.

Sound Rating Scale

Ratings of liking, $F(1, 263) = 202.80$, $q < .001$, $\eta^2 p = 0.50$, quality, $F(1, 163) = 40.26$, $q < .001$, $\eta^2 p = 0.20$, and naturalness, $F(1, 163) = 361.42$, $q < .001$, $\eta^2 p = 0.69$ all showed significant main effects of Environment, with nature sounds eliciting higher liking, quality, and naturalness ratings compared to urban sounds. Nature sounds ($M = 3.66$, $SD = 0.62$) were better liked compared to urban sounds ($M = 2.53$, $SD = 0.53$). Additionally, nature sounds ($M = 3.86$, $SD = 0.70$) were rated as higher quality compared to urban sounds ($M = 3.20$, $SD = 0.78$). As expected, nature sounds ($M = 4.05$, $SD = 0.51$) were also rated to be more ‘natural’ in comparison to the urban sounds ($M = 2.19$, $SD = 0.59$). Furthermore, ratings of liking, $F(1, 163) = 14.95$, $q < .001$, $\eta^2 p = 0.07$, and quality, $F(1, 163) = 97.17$, $q < .001$, $\eta^2 p = 0.37$, both showed a significant main effect for Quality, with degraded sounds relative to unaltered sounds being overall less liked

Figure 2. Three-way interaction of Time, Environment, and Quality.



Note: Panels A and B depicts the change in 3-back performance for unaltered (A) and degraded (B) nature and urban sounds. Panels C and D depict the change in self-reported fatigue for unaltered (A) and degraded (B) nature and urban sounds. Error bars represent plus or minus one standard error of the mean.

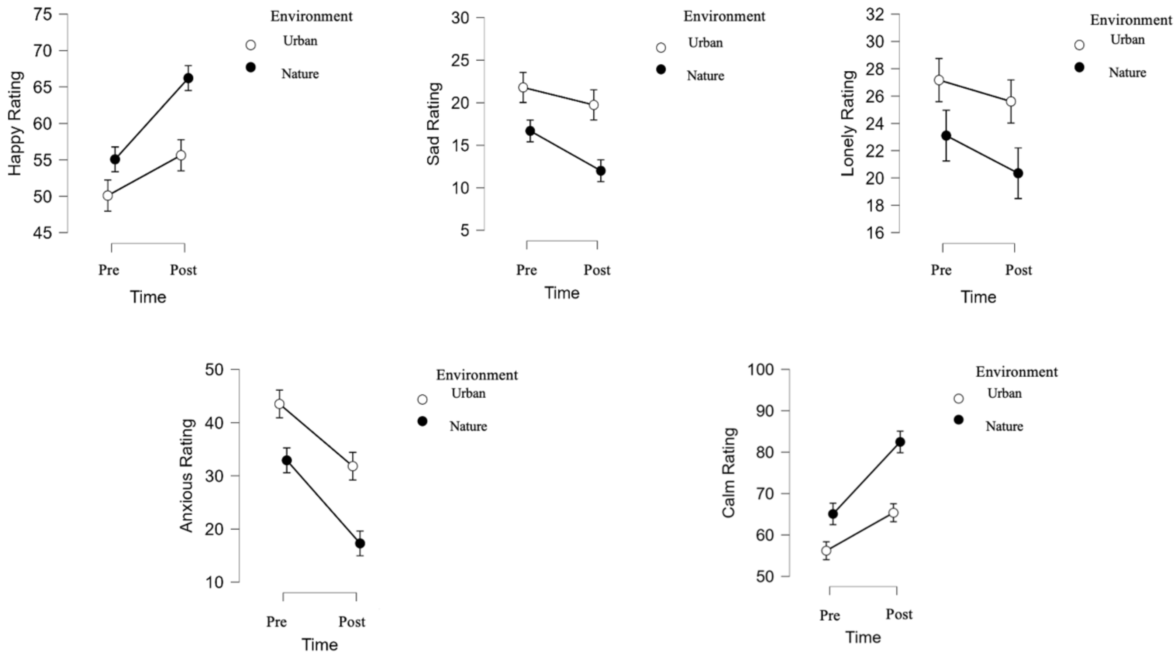
(degraded: M = 2.91, SD = 0.76; unaltered: M = 3.26, SD = 0.82) and judged to be of lower quality (degraded: M = 3.07, SD = 0.81; unaltered: M = 3.92, SD = 0.57). There was no significant main effect of Quality on naturalness ratings; however, the naturalness analysis showed a marginal Environment and Quality interaction, $F(1, 163) = 3.75$, $q = .087$, $\eta^2 p = 0.02$. This interaction was characterized by an attenuation of the relative difference between degraded nature and urban sounds (degraded nature: M = 3.91, SD = 0.50; degraded urban: M = 2.22, SD = 0.53) relative to unaltered nature and urban sounds (unaltered nature: M = 4.16, SD = 0.49; unaltered urban: M = 2.15, SD = 0.64). However, despite this attenuation for degraded sounds, a Tukey's post-hoc test confirmed that degraded nature sounds were still rated as significantly more natural than degraded urban sounds (t = 15.10, p < .001).

Visual Analog Scale

The VAS results, split by Time and Environment, are plotted in Figure 3. Ratings for happiness, $F(1, 200) = 32.22$, $q < .001$, $\eta^2p = 0.14$, sadness, $F(1, 200) = 11.28$, $q = .003$, $\eta^2p = 0.05$, loneliness, $F(1, 200) = 9.32$, $q = .009$, $\eta^2p = 0.05$, calmness, $F(1, 200) = 62.63$, q < .001, $\eta^2p = 0.24$, and anxiety, $F(1, 200) = 10.19$, $q < .001$, $\eta^2p = 0.29$ all showed significant main effects of Time. These main effects were characterized by higher happiness and calmness scores, as well as lower sadness, loneliness, and anxiety scores, in the second administration of the VAS relative to the first.

Analyses on the happiness scores showed an interaction between Time and Environment, $F(1, 200) = 7.67$, $q = .018$, $\eta^2p = 0.04$, with nature sounds leading to significantly higher happiness ratings compared to urban sounds. For the calmness scores, there was also an interaction between Time and Environment, $F(1, 200) = 19.40$, $q < .001$, $\eta^2p = 0.09$, with nature sounds leading to significantly higher calmness ratings compared to urban sounds. Analyses on the anxiety scores also indicated an interaction between Time and Environment, $F(1, 200) = 10.19$, $q = .006$, $\eta^2p = 0.05$, with nature sounds leading to significantly lower anxiety ratings compared to urban sounds. Sadness and loneliness did not show interactions of Time and Environment. Finally, there were no significant interactions of Time and Quality for any of the terms. Calmness and anxiety both showed marginal three-way interactions between Time, Environment, and Quality. These three-way interactions were unexpectedly characterized by *stronger* effects in the degraded conditions (i.e., more pronounced differences between degraded nature and urban sounds compared to unaltered nature and urban sounds). Scores for happiness, sadness, loneliness, and anxiety did not show interactions for Time and Quality.

Figure 3. VAS results.



Note: Error bars represent plus or minus one standard error of the mean.

Perceived Restorativeness Scale

A Pearson correlation was conducted to examine the relationships between the three subcomponents: being away, extent, and fascination. Fascination was found to have a significant relationship with extent, $r(202) = .86$, $q < .001$. Being away was found to be significantly correlated with extent, $r(202) = .79$, $q < .001$ and with fascination, $r(202) = .77$, $q < .001$. Ratings for ‘being away’, $F(1, 200) = 43.33$, $q < .001$, $\eta^2p = 0.18$, ‘extent’, $F(1, 200) = 36.40$, $q < .001$, $\eta^2p = 0.15$, and ‘fascination’, $F(1, 200) = 23.22$, $q < .001$, $\eta^2p = 0.10$ all showed significant main effects for Environment, with nature sounds eliciting higher scores on these factors. Furthermore, ratings for ‘extent’, $F(1, 200) = 5.05$, $q = .076$, $\eta^2p = 0.03$ and ‘fascination’, $F(1, 200) = 4.63$, $q = .084$, $\eta^2p = 0.02$ both indicated marginal main effects for Quality, with unaltered sounds eliciting higher ‘extent’ and ‘fascination’ ratings compared to degraded sounds. No interaction was found between environment and sound quality across the three subcomponents.

Mental Bandwidth Scale

A Pearson correlation examined the relationships between the three subcomponents: self-awareness, daydreaming, and planning. The results found a significant relationship between 'self-awareness' and 'daydreaming', $r(202) = .27$, $q < .001$. 'Planning' was found to be significantly correlated with 'self-awareness', $r(202) = .49$, $q < .001$ and 'daydreaming', $r(202) = .44$, $q < .001$. Analyses on the daydreaming ratings showed a marginal main effect for Quality, $F(1, 200) = 4.67$, $q = .084$, $\eta^2 p = 0.02$. However, the results found no other significant main effects or interactions across the three subcomponents for Environment and Quality.

Discussion

The current study examined the ways in which the perceptual quality of environmental sounds influenced affect and cognitive performance. The results of the study provide evidence for perceived restoration after exposure to nature sounds, despite the specific quality of the sounds. The analyses of the mood ratings revealed a significant interaction between time and environment for ratings of happiness, calmness, and anxiety. Listening to nature sounds resulted in higher levels of happiness and calmness, along with lower levels of anxiety compared to listening to urban sounds. Ratings of self-reported fatigue were also found to significantly increase after listening to urban sounds, as opposed to the nature sounds.

The study found effects of affective restoration despite the fact that participants differentially rated sounds based on the quality. The sound ratings showed that degraded sounds were significantly less liked and were rated to be of significantly lower quality in comparison to unaltered sounds, serving as a manipulation check. However, participants were still able to clearly identify the sounds as natural or urban, and rated the nature sounds as more 'natural' than the urban sounds. The PRS also revealed that the degraded sounds were rated to be marginally lower for ‘extent’ and ‘fascination’. Similarly, the daydreaming subcomponent of the MBS found a marginal main effect for quality, where the degraded sounds were rated lower than the unaltered sounds. Collectively taking these factors into account, the results show clear support for restoration following the exposure to nature sounds. This continues to remain true despite participants recognizing the sounds to be of degraded quality and liking them less than unaltered sounds.

The results of the study provide further insight into how cognitive performance is related to the perceptual quality of sounds. The quality of the sounds was only found to marginally interact with environment in ANB performance. Specifically, performance on the three-back task revealed that exposure to unaltered nature sounds resulted in an increase in performance. However, performance was found to decrease after listening to unaltered urban sounds. This finding is consistent with prior research which has found improvements in cognitive performance following the exposure to nature stimuli, but not urban stimuli (Berman et al., 2008; Van Hedger et al., 2019a). In contrast, exposure to degraded nature sounds and degraded urban sounds both resulted in a weak increase in performance. These results suggest that the nature-related benefits for cognitive performance rely heavily on the quality of the sounds. In order to observe major changes in performance on cognitive tasks, the results indicate that an increase in perceptually rich stimuli may help achieve this. Overall, nature sounds were perceived to be restorative on a variety of dimensions, including self-reported mood, self-reported restoration, and self-reported fatigue, and these measures were found to be insensitive to sound quality. Further, unaltered nature sounds displayed the ability to improve cognitive performance, which indicates that performance-based cognitive restoration requires exposure to high sound quality.

The results of the current study have interesting implications for Attention Restoration Theory (ART; Kaplan, 1995). The PRS scores indicated that participants rated nature sounds to be higher across the three subcomponents: being away, extent, and fascination. Participants also rated unaltered sounds marginally higher for ‘extent’ and ‘fascination’, in contrast to degraded sounds. The results of the PRS suggest that participants were able to identify the sound quality and were sensitive to the reduced restorative qualities of degraded sounds. However, this was not seen to significantly influence changes in affect and self-reported fatigue. Therefore, participants appeared to experience a sense of perceived affective and cognitive restoration (assessed via self-reported fatigue) for degraded nature sounds that was statistically comparable to unaltered nature sounds, despite recognizing the degraded sounds to be reduced in terms of several restorative dimensions. This finding is in line with previous research conducted by Van Hedger et al. (2019b), in which heavily degraded sounds were seen to be aesthetically preferred given that the sounds could still be recognized as originating from natural environments. Consequently, the results suggest that degraded nature sounds possess the ability to show restorative benefits on self-reported affect.

In contrast to the restorative influence of degraded sounds on affect, the results of the performance on the ANB task indicate that the dimensions of ART may play a crucial role in modifying cognitive performance. The benefits of nature on performance on the ANB task were driven by the quality of the sound, and more specifically, the unaltered version of the sounds. These findings can potentially be attributed to the use of low-level perceptual features of the degraded sounds and their influence on perceived naturalness (Berman et al., 2014). Perceptions of natural environments have been found to be consistent in terms of perceptual features of nature (Berman et al., 2014). As a result, the process of degrading nature sounds involves removing perceptual features which may be critical for performance-based cognitive restoration. The removal of such perceptual features may also lead to the removal of important perceptual features that contribute to cognitive restoration beyond solely identifying the sound as either natural or urban.

The findings of the study are also in accordance with Stress Reduction Theory (SRT; Ulrich, 1991). Although the current study did not directly measure stress levels in participants, changes in affect — including calmness and anxiety — were evidently observed. The results from the VAS indicated that exposure to nature sounds resulted in higher scores for happiness and calmness, and lower scores for anxiety in comparison to exposure to urban sounds. Furthermore, listening to nature sounds resulted in higher levels of restorativeness in terms of eliciting feelings of ‘being away’, ‘extent’, and ‘fascination’. Collectively, these findings show an increase in positive affect and a decrease in negative affect following the exposure to nature sounds. The findings may also indicate that higher levels of restoration may potentially be related to lower levels of negative affect. Previous research has also suggested a possibility of an association between high levels of restorativeness and lower levels of negative affect, such as stress (Payne et al., 2020).

The results of the present study are consistent with previous research, in which presentations of nature and conceptual exposure to natural environments have been examined. For instance, Felsten (2009) assessed the influence of nature depicted murals on restoration and cognitive fatigue, where participants were exposed to either no views of nature, window views of nature, or nature murals. When presented with a setting involving vivid nature murals, such views were rated to possess higher restorative potential in comparison to window views of real nature (Felsten, 2009). Similarly, a study by Nejati et al. (2016) examined the use of visual simulation and nature depicted artwork in hospital settings involving staff break rooms. Nurses judged the restorative qualities of an outdoor view from a balcony or window, nature artwork, and an indoor plant. Nature depicted artwork was found to have higher restorative qualities compared to indoor plants, and also increased the restorative potential of the staff break rooms in contrast to areas with no nature artwork (Nejati et al., 2016). Although viewing nature murals and nature depicted artwork does not involve direct contact and exposure to nature, artistic and simulated depictions of nature have continued to be shown to be restorative.

Such findings once again suggest that despite the low-level perceptual presentation of nature, the restorative effects of nature may continue to be relatively robust and individuals may still be able to reap the benefits of nature. Due to the lack of perceptual richness, these nature-related benefits may be attributed to the ability to identify the sounds as nature. This is consistent with previous research, in which nature sounds were aesthetically preferred over urban sounds as long as individuals were able to identify the sounds as being derived from a natural environment (Van Hedger et al., 2019b). Therefore, a crucial aspect of experiencing a sense of restoration involves the conceptual activation of nature as a category.

The present study is not without limitations. Firstly, the online nature of the study may have resulted in different experiences among the participants. An online sample has the potential to increase the variability in participant experiences of listening to the assigned sounds. This may be due to individual preferences of wearing headphones and the differences in clarity of the specific sounds on their electronic device. Despite this, the results of the study found multiple significant effects of nature sounds compared to urban sounds. However, greater control over the variability in listening experiences may have allowed for the sounds to be better characterized in terms of effect sizes. Reduced variability in listening experience would result in a clearer understanding of the participants' interpretation of nature and urban sounds. Additionally, the online nature of the study may have influenced performance on the ANB task, as factors such as concentration levels, distractions, and individual surroundings may play a role in one's performance. Similar to the listening experiences, controlling the surroundings in which the ANB task was completed would perhaps lead to conditions in which the results of task performance would be enhanced, and the relative effects of each sound type on ANB performance could be further clarified. Although such experiences of an online sample were not controlled, the current study's sample was shown to be diverse and consisted of a wide range of ages. In order to address the current study's limitation of the lack of control over participants' listening and ANB task experience, it would be beneficial to conduct the study in a controlled environment to ensure that performance remains uninfluenced by external factors.

Another limitation of the study involves the representation of environments using a nature and urban dichotomy. Representing nature and urban environments as completely separate categories may incorrectly suggest that there is no variability that exists within each environment, or that no overlap exists between the two environments. Nature and urban environments often share various perceptual features within each environment, and such features may result in different experiences of restoration. Nature and urban environments should instead be viewed on a continuum, in which a wide range of environments may consist of specific features that may be considered to be either natural or urban (Brancato et al., 2022). Therefore, utilizing a nature-urban dichotomy does not allow for a deeper and nuanced understanding of how environmental sounds may be associated with affective and cognitive restoration, as these sounds may fall along a nature-urban continuum. Although natural sounds were generally found to result in feelings of restoration, specific elements of nature sounds may also lead to varied levels in which cognitive resources are restored. For instance, nature sounds involving insects may elicit a different effect of restoration in comparison to nature sounds which involve running water. Furthermore, environmental sounds which do not explicitly stem from a natural environment, but fall somewhere along a nature-urban continuum, could potentially still exhibit effects of restoration. However, the use of a nature-urban dichotomy does not provide insight into such effects.

Future research would benefit from depicting natural environments along a continuum, rather than classifying it as a rigid category. Doing so would allow research to examine a wide range of environments and their restorative potential, rather than the classical representation that is commonly held of nature. Characterizing nature along a continuum would further allow for a better understanding of the specific perceptual features which lead to nature-related benefits, and the importance of such features in resulting in a restorative experience. This characterization will also provide insight into how the specific components of ART play a role in a wide range of environments, and how these components may vary depending on the environment.

A third limitation is the way in which the study solely uses environmental sounds as a medium to examine the influence of perceptual quality on cognitive and affective restoration. Although converging results were found regarding the effects of unaltered and degraded sounds on multiple measures of restoration, it is currently unclear how such findings could be applied to visual or multimodal presentations of environments. Despite the fact that exposure to natural environments in the real world involves auditory components, it is also true that it involves additional perceptual qualities. Exposure to nature often involves a multisensory and multimodal experience, which the current study does not account for. Due to this, it is uncertain whether the results of this study would translate over to visual or audiovisual presentations of nature. For instance, a presentation of degraded and unaltered images of nature may result in a different immersive and restorative experience. Similarly, although audiovisual presentations of nature may capture more than one sensory quality, the current results cannot provide insight into how such degraded or unaltered presentations may influence restoration. As a result, the current study's use of auditory presentations of environments results in a low generalizability to multimodal experiences of nature. Future research should examine how lower-quality representations of nature through different domains may influence nature-related benefits on cognitive and affective restoration. A focus on degraded and unaltered images of nature, for example, will help in gaining a better understanding of the influence of perceptual richness in experiencing the benefits of nature, and whether such effects are consistent throughout different domains.

An additional factor which future research should consider involves the order that the procedure of the study is conducted in. The current study measures happiness, sadness, calmness, anxiety, and loneliness immediately after participants are exposed to the sounds, followed by the completion of the ANB. Administering the VAS additionally after the second completion of the ANB may provide insight into the strength of the effects of nature sounds, and whether affective restoration continues to be experienced following a cognitively challenging task. A procedure which takes such factors into account can more clearly demonstrate the duration of affective restoration following the exposure to nature sounds, and whether a cognitively demanding task reduces such nature-related benefits on affect.

Despite the aforementioned limitations, the findings of the study have interesting implications for ART and nature-related experiences. The results of the study indicate that regardless of the quality of the sounds, nature sounds have the ability to improve affect and attenuate the fatigue felt after completing a challenging cognitive task. Consequently, experiencing a sense of affective restoration and self-reported cognitive restoration may not be driven by the perceptual quality of the environment. Although ART posits that an environment must be highly immersive and perceptually rich in order for one to experience feelings of ‘being away’, ‘extent’, or ‘fascination’, the current study indicates that this may not be as critical for affective restoration. Provided that individuals recognize the sounds and are able to categorize them as originating from nature, an improvement in affect can be seen. However, in order to observe similar effects in cognitive performance, the components of ART may play a more crucial role. An improvement in cognitive performance may require a perceptually rich and highly immersive environment in order to effectively restore mental resources. This is indicated by the results of the three-back task, in which performance was found to improve after participants listened to unaltered nature sounds in comparison to when participants listened to degraded sounds. Therefore, although affective restoration can be experienced through the exposure of both unaltered and degraded nature sounds, performance-based cognitive restoration may rely more heavily on the high perceptual richness of the sound.

Conclusion

The current study contributes to the understanding of the influence of the quality of nature sounds on cognitive and affective restoration. Through the use of degraded and unaltered environmental sounds, the study examined changes in cognitive performance and affective state.

Participants reported experiencing higher levels of restorativeness and improved mood after listening to nature sounds in contrast to urban sounds. This effect was seen regardless of the quality of the nature sounds, despite participants evidently recognizing the degraded sounds as lower quality and liking them less. Such findings regarding affective restorativeness are also in line with prior research. Performance on the ANB task was found to be dependent on the quality and the specific environment of the sounds. An increase in performance was seen following the exposure to unaltered nature sounds, while a decrease in performance was seen following the exposure to unaltered urban sounds. The findings of the study suggest that perceptually richer stimuli may be necessary in order to observe changes in performance-based cognitive measures of restoration. However, this may not be the case for affective restoration as affect was found to be uninfluenced by the quality of the sounds, and degraded sounds were even found to show stronger effects of nature on dimensions of calmness and anxiety. In order to further examine the effects of lower quality stimuli on cognitive and affective restoration, future research should determine whether such effects are consistent throughout different domains and representations of environments.

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Curriculum Vittae

Name:	Huda Ahmed
Place and Year of Birth:	Thunder Bay, Canada, 2000
Secondary School Diploma:	Australian International School, Sharjah, United Arab Emirates (2018)
Post Secondary Diploma:	Bachelor of Arts, Honours Specialization Psychology, Huron University College (Expected Graduation 2022)
Experience:	Early Learning Centre Volunteering, 2017
	Nursing Home Volunteering, 2018
	Huron University Fall CURL Conference, 2021
Scholarships and Awards:	Huron Entrance Scholarship, 2018
	Huron Achievement Award, 2018
	Dean's Honour List, 2020