5-2023

Does watching videos with natural scenery restore attentional resources? A critical examination through a pre-registered within-subject experiment

Andree HARTANTO
Singapore Management University, andreeh@smu.edu.sg

Nicole Lee Anne TEO
Singapore Management University, nicole.teo.2019@socsc.smu.edu.sg

Verity Y. Q. LUA
Singapore Management University, verity.lua.2021@msps.smu.edu.sg

Keith TAY
Singapore Management University, keith.tay.2018@socsc.smu.edu.sg

Nicole R. Y. CHEN
Singapore Management University, nicolechen.2021@msps.smu.edu.sg

See next page for additional authors

Citation

HARTANTO, Andree, TEO, Nicole Lee Anne, LUA, Verity Y. Q., TAY, Keith, CHEN, Nicole R. Y., & MAJEED, Nadyanna M..(2023). Does watching videos with natural scenery restore attentional resources? A critical examination through a pre-registered within-subject experiment. *Experimental Psychology, 70(2)*, 96-107.
Available at: https://ink.library.smu.edu.sg/soss_research/3773

Author

Andree HARTANTO, Nicole Lee Anne TEO, Verity Y. Q. LUA, Keith TAY, Nicole R. Y. CHEN, and Nadyanna M. MAJEED

Published in Experimental Psychology (2023) 70 (2), 96-107. DOI: 10.1027/1618-3169/a000578

Does Watching Videos with Natural Scenery Restore Attentional Resources? A Critical Examination through a Pre-registered Within-subject Experiment

Andree Hartanto[1], Nicole Lee Anne Teo[1], Verity Y. Q. Lua[1], Keith Tay[1], Nicole R. Y. Chen[1], & Nadyanna M. Majeed[2]

[1] Singapore Management University

[2] National University of Singapore

Address correspondence to:
Andree Hartanto, Ph.D.
Singapore Management University
School of Social Sciences
10 Canning Rise, Level 5
Singapore 179873
Emails: andreeh@smu.edu.sg
Phone: (65) 6828 1901

Acknowledgements

This research was supported by a grant awarded to Andree Hartanto by Singapore Management University through research grants from the Ministry of Education Academy Research Fund Tier 1 (21-SOSS-SMU-023) and Lee Kong Chian Fund for Research Excellence. The authors declare that there is no conflict of interest.

Abstract

Existing studies have shown that direct exposure to a real nature environment has a restorative effect on attentional resources after a mentally fatiguing task. However, it remains unclear whether virtual nature simulations can serve as a substitute for real nature experienced in the outdoors to restore executive attention. Given the mixed findings in the literature, the present study sought to examine if viewing videos with natural scenery (vs. a control with urban scenery) restores participants' working memory capacity – measured by an operation span task – in a high-powered pre-registered within-subject experimental study. Overall, our within-subject experiment did not find any evidence to support the benefit of watching videos with natural scenery on restoration of executive attention. Moreover, results from our Bayesian analyses further showed substantial support for the null hypothesis. Our study suggests that virtual nature simulations, even with the use of videos, may not be able to replicate the experiences of nature in the outdoors and restore attentional resources.

Keywords: exposure to nature, virtual nature simulations, attention restoration, working memory capacity, pre-registered experiment, within-subject design

Does Watching Videos with Natural Scenery Restore Attentional Resources? A Critical Examination through a Pre-registered Within-subject Experiment

Man shares an intimate connection with nature. Aside from the provision of physical resources for survival (Pimentel & Pimentel, 2003), nature also offers many intangible and psychological benefits to humankind (Barnes et al., 2019; Bratman et al., 2012; Gillis & Gatersleben, 2015; Houlden et al., 2021; Hunt et al., 2020; Kaplan, 2001; Mayer et al., 2009). This phenomenon has led to the emergence of a range of studies examining the socioemotional benefits of exposure to nature (Berman et al., 2008; Huynh et al., 2013; Weeland et al., 2019; White et al., 2019). Specifically, exposure to nature has been consistently shown to be associated with higher levels of subjective well-being and lower levels of anxiety, depressive symptoms, perceived stress, and suicidal tendency (Bratman et al., 2019; Pasanen et al., 2018; Pritchard et al., 2020; White et al., 2017; Yeung & Yu, 2022). In a similar pursuit of comprehensively understanding the benefits of nature, numerous studies have also found a positive effect of exposure to nature on cognitive functioning, particularly on attentional control, in a variety of samples ranging from children to older adults (Faber Taylor & Kuo, 2009; Gamble et al., 2014; Goh et al., 2023; Palanica et al., 2019; Schertz & Berman, 2019; Stevenson et al., 2019; Tennessen & Cimprich, 1995).

The positive effect of exposure to nature on cognitive functioning is in line with Kaplan's (1995) Attention Restoration Theory, which postulates that nature has a restorative effect on an individual’s attention after a mentally fatiguing task. According to the theory, while majority of goal-directed tasks require effortful control, the experience of nature merely requires effortless attention and activates brain structures that are distinct from the brain structures used for directed attention (Kaplan & Berman, 2010). As a result, paying effortless attention to nature thus “restores” one’s attention and improves one’s performance once they return to the initial task or start another mentally fatiguing task. According to Kaplan (2001), this restorative effect is mediated by four factors: fascination, being away, extent and compatibility. Firstly, the environment must generate fascination in the person such that he or she is then able to effortlessly direct his or her attention to it. Secondly, the environment must generate a feeling of being away from one's current thoughts and concerns; this does not imply that the person must be physically away from the present environment. Thirdly, the environment must have extent or the ability to generate a feeling of engagement in people due to its familiarity, which is in turn a result of the consistency of its elements. Lastly, the environment must have compatibility, determined by its synergy with a person's aims and taste. The experience of a natural environment with all four characteristics is argued to produce a more effective restorative effect for attention in people who are mentally fatigued.

Besides the Attention Restoration Theory, there are also several other theories that have been proposed to explain the cognitive benefits of exposure to nature via the role of affective states (Schertz & Berman, 2019). For instance, Stress Reduction Theory (Ulrich 1983) postulates that exposure to nature elicits positive emotional response that allows individuals to return from a stressful state to an unstressed state, resulting in a reduction in stress and negative affect while increasing positive affect. The stress reduction would then maintain and enhance individuals' cognitive functions. Similarly, according to the Perceptual Fluency Account (Joye & van den Berg, 2011), natural environments tend to be easy to process and understanding compared to more urban or man-made environments, leading to higher perceptual fluency and effortless processing. The effortless processing then leads to higher positive affect, which in turn improves cognitive functions (Storbeck & Maswood, 2016; Yang et al., 2013).

In line with the attention restoration theory, studies have consistently shown that exposure to nature restores attentionally-demanding cognitive performance after a mentally fatiguing task (e.g., Faber Taylor & Kuo, 2009; Gamble et al., 2014; Stenfors et al., 2019; Stevenson et al., 2019; Tennessen & Cimprich, 1995). For example, Berman et al. (2008; Study 1) found that participants who took a 50-minute walk in a natural environment after a series of demanding cognitive tasks had higher working memory capacity compared to those who took a 50-minute walk in an urban environment. In another experiment, Berman et al. (2012) showed that a 50-minute walk in a natural environment as compared to in an urban environment enhanced working memory capacity in participants with major depressive disorder. The cognitive benefits of walking in a natural environment were also successfully replicated in a number of replication studies by other researchers (e.g., Bratman et al., 2015; Hartig et al., 2013).

Beyond the cognitive benefits of direct exposure to a real nature environment, studies have also suggested that virtual nature simulations, such as viewing pictures of nature settings (e.g., Berman et al., 2008, Study 2; Berto, 2005; Gamble et al., 2014), as well as listening to nature sounds (e.g., Van Hedger et al., 2018), may also improve cognitive performance. For instance, Berman et al. (2008, Study 2) found that participants who viewed pictures of nature environments as compared to urban environments had enhanced executive attention, measured by the backward digit span and attention network tasks. The findings were further replicated by Gamble et al. (2014) in older adults. In Van Hedger et al. (2019), their study found a greater improvement in cognitive performance operationalized by the n-back and backward digit span tasks after being exposed to nature sounds compared to the urban condition. Moreover, exposure to virtual nature such as virtual reality (e.g., Frigione et al., 2022; Li et al., 2021; Valtchanov et al., 2010) and nature videos (e.g., McAllister et al., 2017) have been shown to increase positive affect and lower negative affect. These findings have important implications given the economic efficiency and convenience of virtual nature simulations as a form of cognitive intervention.

However, the effect of virtual nature simulations on cognitive functions has not always shown themselves to be consistent. For example, several recent studies have reported failures to replicate the effect of viewing pictures of natural environments on cognitive functions (Cassarino et al., 2019a; Emfield & Neider, 2014; K. A. Johnson et al., 2022; Kuziek, 2017; Neilson et al., 2021). Bourrier et al. (2018) did not find any evidence of improved executive attention operationalized by the n-back task when comparing between viewing nature, urban and no video conditions. Similarly, Cassarino et al. (2019a) failed to find any difference in sustained attention measured by the Sustained Attention to Response Task (SART) between participants who were exposed to rural or urban road environments using a virtual reality simulator (see Frigione et al., 2022 for similar null effect in cognitive outcome). In fact, a recent meta-analysis showed that simulated nature does not reliably restore executive attention across 14 experimental studies (Johnson et al., 2021).

In view of the mixed findings, the current study aimed to revisit the positive effect of virtual nature simulations on cognitive functions and investigate whether virtual nature simulations can serve as a substitute for real nature experienced in the outdoors. To increase the sensitivity of the current study to detect the effect of virtual nature simulations, we made three important modifications. First, we employed a pure within-subject experimental approach with a large sample to increase our statistical power and minimize errors due to individual differences (Charness et al., 2012). Second, we focused on working memory capacity measured by the complex span task, which has been shown to display high reliability and has been shown to place high demands on executive attention (Foster et al., 2015; Kane et al., 2001; McCabe et al., 2010; Unsworth et al., 2009). More importantly, working memory capacity measured by complex span task was found to predict many important outcomes including fluid intelligence, quality of life, social functioning, moral judgement, academic achievement, and work performance (Conway et al., 2003; Gao et al., 2016; Gathercole et al., 2004; Lemonaki et al., 2021; Moore et al., 2008; Pollard & Courage, 2017; Vaughan & Laborde, 2021). Lastly, instead of using pictures, we chose to use videos, which included realistic and engaging visual and auditory stimuli, to replicate the experiences of nature with relatively higher level of immersion. We chose to use video rather than virtual reality due to their accessibility, economically efficiency, and convenience to the general public, allowing it to be a more readily available cognitive intervention. Taken together, based on attention restoration theory, we hypothesized that exposure to videos with natural scenery would significantly restore participants' executive attention, indexed by working memory capacity in operational span, as compared to videos depicting urban scenery.

Method

Study Design

The current study utilized a 2 (condition: nature video vs. urban video) × 2 (time: before watching video vs. after watching video) fully within-subject experimental design. The within-subject approach was chosen as it increases statistical power and decreases error rates caused by individual differences by accounting for interpersonal variability (Charness et al., 2012; Hartanto et al., 2020). To reduce the occurrence of carry-over effects, such as practice or placebo effects that may arise in within-subject experiments, counterbalancing was carried out. Random assignment by Qualtrics was used to determine the order in which each participant was exposed to the two different conditions.

Participants

While our a priori power analysis using G*Power 3.1 (Faul et al., 2007) showed that the minimum sample size required for a repeated measures ANOVA to observe an effect size of $F = 0.25$ with 80% power is $N = 34$, we strove to maximize our statistical power and hence recruited as many participants as possible. A total of 155 participants from a local university in Singapore were recruited for the current study, slightly over our pre-registered sample size of 150. All of the participants were undergraduates. The data was collected during the semester before exam times and participants were compensated with course credits for their research participation. As in our pre-registered data collection plan, one participant was removed from the study after Session 1 for failing the attention check presented right after the video manipulation. Three participants failed to return for Session 2 (attrition = 1.94%), and a further three participants entered participant IDs that could not be matched to their responses in Session 1. As such, only data from a total of 148 participants (95.48% retention) were available for analysis.

As per our pre-registered exclusion criteria, a further three participants were excluded from data analysis for attaining less than 65% accuracy on the distractor questions[1] on any of the four operation span tasks they completed across both sessions. Lastly, the data of six participants were removed due to each participant spending more than an hour on either session.[2] Thus, the final analytic sample consisted of 139 participants (70.80% female). All participants provided informed consent to participate in the study prior to the onset of the experiment. Data collection was approved by the local Institutional Review Board [IRB-20-123-A078(1020)].

Procedure and Materials

Participants completed the entire study online for either 2 course credits or monetary compensation of SG$5. The study comprised two sessions spaced a week apart, and was conducted entirely online using Qualtrics. Both sessions had a similar flow (Figure 1). Ten to

[1] A relatively lenient cutoff of 65% was imposed as the study was conducted completely online.
[2] While the removal of participants due to excessive time spent was not pre-registered, we felt that their data should still be removed given that the sessions could very conceivably be completed in under an hour. Additional analyses conducted with the inclusion of these six participants (total N = 145) were consistent with the results presented in the current work (N = 139).

15 minutes prior to the start of each session, participants were sent an email containing a study link and instructions to complete the study on a laptop or desktop in a quiet and conducive environment with good Wi-Fi and with earpieces. Participants provided informed consent immediately prior to the start of the first session, and performed an audio check at the beginning of each of the sessions.

Following the audio check, participants completed the Positive and Negative Affect Schedule (PANAS; Watson et al., 1988) to measure state affect. Participants were given a list of 20 items, with positive affect (e.g., *interested, excited*; $\alpha_{session1pre} = .93$, $\alpha_{session2pre} = .94$) and negative affect (e.g., *upset, distressed*; $\alpha_{session1pre} = .86$, $\alpha_{session2pre} = .90$) represented by 10 items each. Participants were asked to rate how much they felt each item "at the moment" on a 5-point scale (1 = *Very Slightly or Not at All*, 5 = *Extremely*). Affect was studied as an exploratory outcome because exposure to pictures and videos of nature has been shown to increase positive affect (Mayer et al., 2009). Hence, it was not pre-registered.

After completing the PANAS, the dependent variable of interest, working memory capacity, was measured via the operation span task (Figure 2; Foster et al., 2015; La Pointe & Engle, 1990; Redick et al., 2012; Quek et al., 2021). The task was selected given that performance on it has been shown to be malleable, in that it can be improved with training or otherwise modified by various interventions (Foster et al., 2017; Gallant et al., 2016; Harrison et al., 2013; Quek et al., 2021; Storbeck & Maswood, 2016; Yang et al., 2013). More importantly, several existing studies that found significant cognitive effects of nature have similarly employed the operation span task with a comparable number of trials (e.g., Bratman et al., 2015; Jamrozik et al., 2019). In this task, participants were asked to solve mathematical equations while simultaneously memorizing a series of two-digit, three-syllable numbers (e.g., 28). Each set contained four to six equation-number pairs. Hence, there were three possible set sizes for participants to complete. After each set, participants attempted to recall as many of the two-digit, three-syllable numbers as possible. Working memory capacity was then computed for each participant by partial credit unit (PCU) score, calculated by dividing the amount of correctly recalled numbers by the total amount of numbers presented within each set, and then taking the participant's mean score across all sets (Conway et al., 2005; $\alpha_{session1pre} = .73$, $\alpha_{session2pre} = .81$). Higher PCU scores represented better working memory capacity. Before performing the actual task, participants were given two sets of three equation-number pairs to complete as practice trials to familiarize themselves with the task.

Figure 1

Session Flow

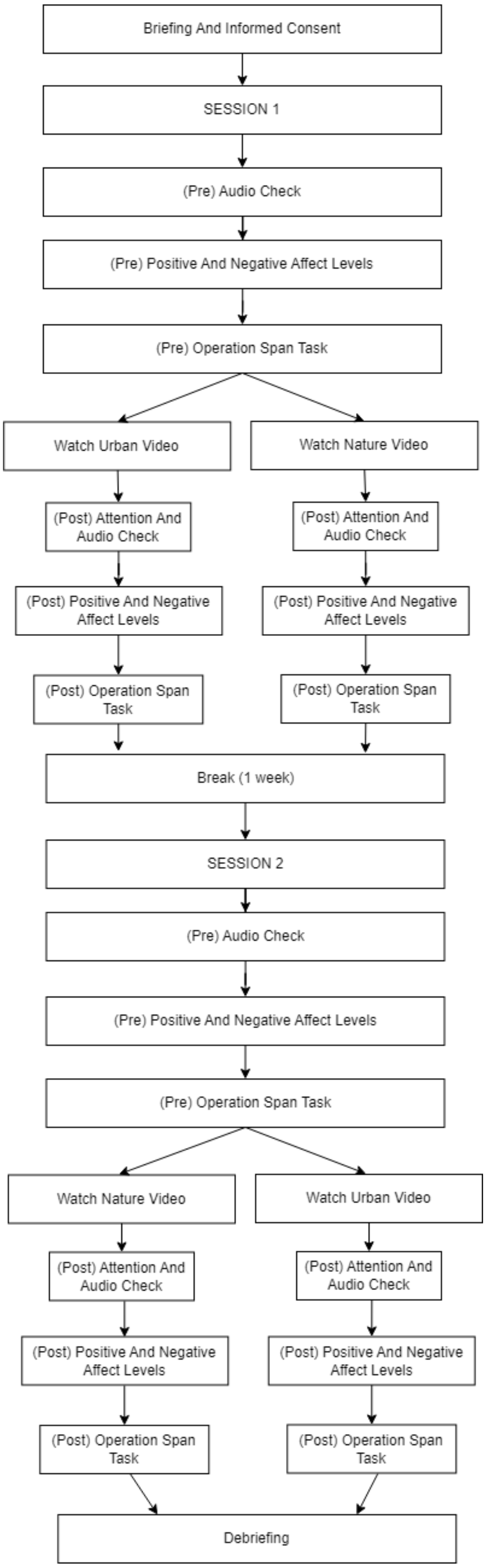
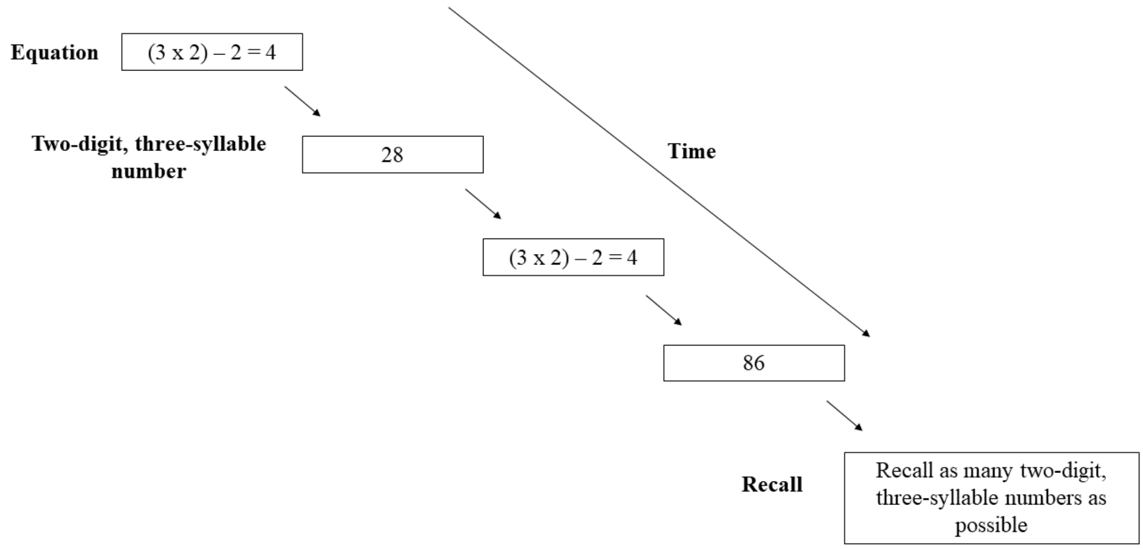


Figure 2

Operation Span Task



After completing the operation span task, participants were instructed to check that their headphones were plugged in and set to approximately 40% volume to ensure that they could hear the audio of the videos. Additionally, they were told to watch the videos in full screen mode and to refrain from using their mobile phones to ensure that their attention was focused solely on the videos. Participants were also informed of a forthcoming attention check which they were required to pass to receive their remuneration. They then went on to view the video they were assigned to for the session. The nature and urban videos were selected by the first and third authors specifically for the current work, based on descriptions of video stimuli used in a previous study which found positive effects of virtual nature exposure on task performance and long-term memory (Pilotti et al., 2015). To control for novelty, both the nature and urban videos depicted foreign (i.e., non-Singaporean) landscapes. The nature video depicted the first-person view of a person walking down a forest path. There were almost no other people along the forest path, and the path was wide and even enough for the cameraman to navigate through without hiking equipment. There were also no animals featured in the video. The audio of the video primarily included footsteps of the camera person and natural sounds (e.g., soft sounds of insects chirping). The urban video depicted the first-person view of a person walking down the street of a busy city. There were many other pedestrians and cyclists sharing the path with the camera person, and there were many cars on the road. There were high rise buildings on both sides of the city's street, and the camera person crossed numerous traffic junctions throughout the journey. The audio of the urban video comprised of noise from vehicles on the street, footsteps of fellow pedestrians, and voices of people conversing on the walkway. Each video was exactly 10 minutes long. This duration was decided based on previous work suggesting that exposure to approximately six minutes of nature pictures were enough to evidence improvements on cognitive tasks (e.g., Berman et al., 2008; Gable et al., 2014). To err on the side of caution, we choose to expose participants to the videos for 10 minutes instead of six. Participants were only able to progress with the rest of the survey after this time had elapsed.

To ensure good data quality, participants completed a simple attention check measure, which was a question asking whether or not it rained in the video. Additionally, participants were asked to report whether they could hear the audio of the video. Following the checks, participants were again asked to fill in the PANAS (positive affect: $\alpha_{session1post} = .92$, $\alpha_{session2post} = .93$; negative affect: $\alpha_{session1post} = .83$, $\alpha_{session2post} = .91$), and again completed the operation span task ($\alpha_{session1post} = .79$, $\alpha_{session2post} = .82$). Participants were fully debriefed about the purpose of the study at the end of their second session.

Transparency and Openness

The current study's design and analysis plans were pre-registered. The pre-registration, data, and analytic code have been made publicly available on ResearchBox #861 (https://researchbox.org/861). Frequentist analyses were conducted in R version 4.2.0 (R Core Team, 2020), using various packages. Specifically, descriptives and scale reliabilities in the form of Cronbach's α were calculated using psych version 2.2.5 (Revelle, 2021), ANOVAs and calculation of corresponding effect sizes were conducted using rstatix version 0.7.0 (Kassambara, 2021), and data visualization was carried out using ggplot2 version 3.3.6 (Wickham, 2016). We also conducted Bayesian analyses using JASP version 0.16.3 (JASP Team, 2022) to examine evidence for null effects.

Results

Confirmatory Analyses on Working Memory Capacity

According to our pre-registered analytic plan, we tested for differences in pre- and post-test measures of working memory capacity across both conditions via a 2 (condition: nature video vs. urban video) × 2 (time: before watching video vs. after watching video) repeated measures ANOVA (Table 1). We found that the main effect of the condition on PCU score was not statistically significant, $F(1, 138) = 0.58$, $p = .448$, $\eta_p^2 = .004$. PCU scores in the nature condition ($M = 2.79$, $SD = 1.44$) and in the urban condition ($M = 2.86$, $SD = 1.51$) were not significantly different, suggesting that the type of video watched by the participants did not have any significant effect on their overall PCU scores. In addition, the main effect of time on PCU scores was also not statistically significant, $F(1, 138) = 1.58$, $p = .212$, $\eta_p^2 = .011$. PCU scores at pre-test ($M = 2.79$, $SD = 1.43$) and at post-test ($M = 2.86$, $SD = 1.51$) were not significantly different, suggesting that whether the participants did the test before or after watching the video did not have any significant effect on their overall PCU scores.

Most importantly, we found that the interaction between condition and time on PCU scores was also not statistically significant, $F(1, 138) = 1.60$, $p = .208$, $\eta_p^2 = .011$ (Figure 3). There was no evidence for a difference between the change from pre-test ($M = 2.70$, $SD = 1.37$) to post-test ($M = 2.87$, $SD = 1.51$) under the nature condition and the change in pre-test ($M = 2.87$, $SD = 1.50$) to post-test ($M = 2.85$, $SD = 1.52$) under the urban condition in terms of PCU. This suggests that the type of video watched by the participants did not produce any significant difference in the change in PCU scores from pre-test to post-test.

Table 1

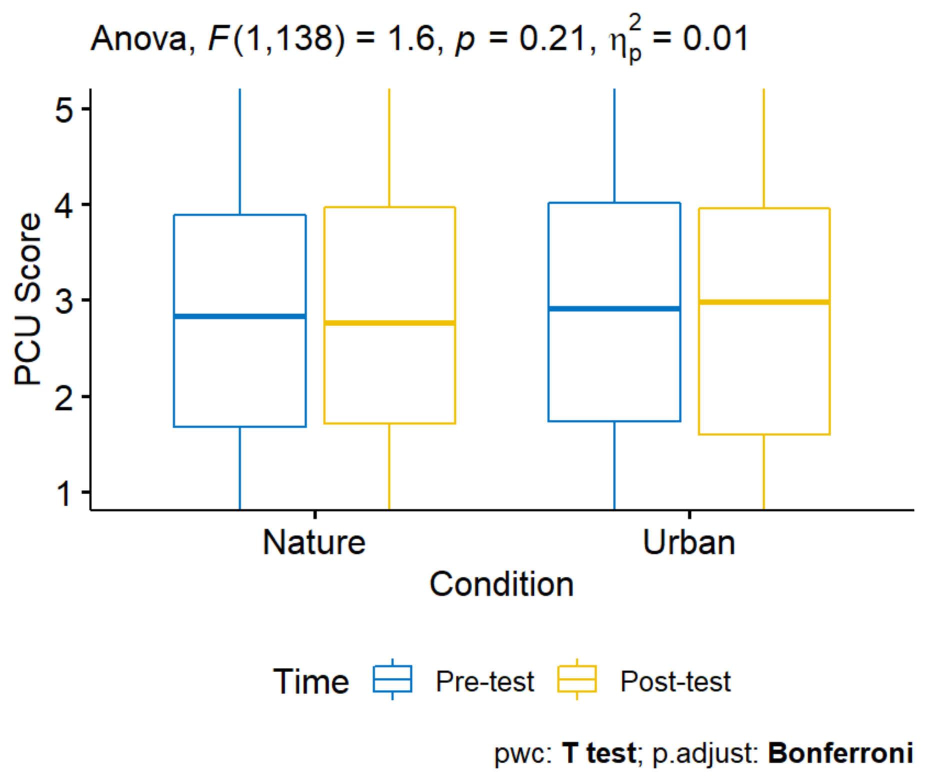
Effects of Time and Condition and Interaction on PCU Scores and Affective Outcomes

	PCU			Positive Affect			Negative Affect		
Predictor	η_p^2	F(1, 138)	p	η_p^2	F(1, 138)	p	η_p^2	F(1, 138)	p
Time	.011	1.58	.212	.354	75.73	<.001	.037	5.24	.024
Condition	.004	0.58	.448	.005	0.74	.392	.004	0.53	.467
Time × Condition	.011	1.60	.208	.024	3.38	.068	.068	10.08	.002

Note. N = 139.

Figure 3

Box Plot Comparing Pre- and Post-test PCU Scores in Both Conditions



To investigate the support, or lack thereof, for the null hypothesis of the interaction, a Bayesian[3] repeated measures ANOVA was conducted. Specifically, we tested the same alternative model—where PCU score was predicted by time, condition, and their interaction—against a null model where PCU score was only predicted by time and condition (i.e., without the interaction). We found anecdotal evidence for the null hypothesis, BF_{01} = 2.81, implying that the null model was almost three times as likely to be true as the alternative model. This corroborated our previous findings suggesting that the type of video watched had no significant effect on the difference between pre- and post-test PCU scores.

Exploratory Analyses on Affective Outcomes

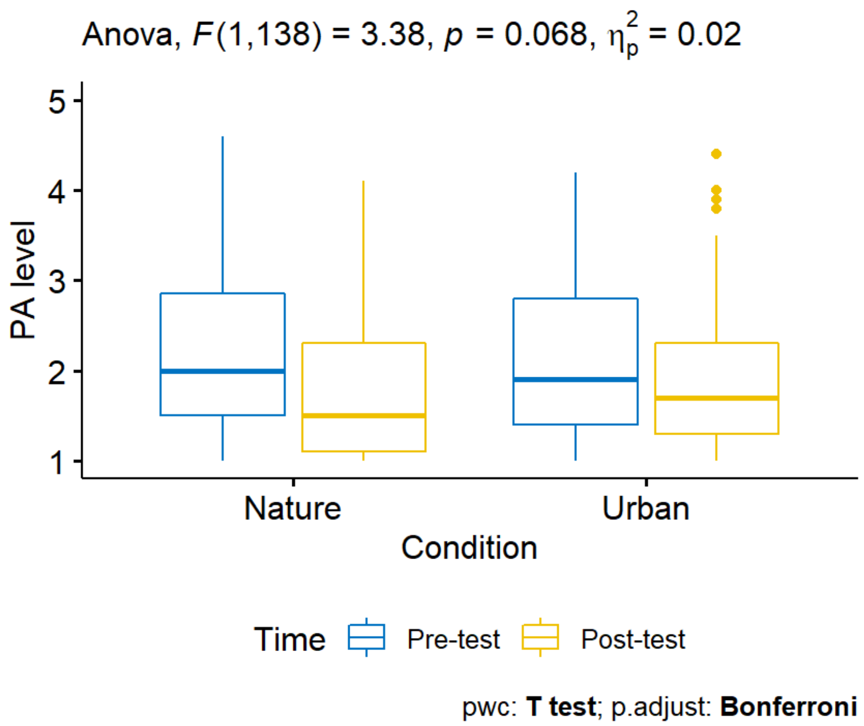
For exploratory purposes, we also conducted two 2 (condition: nature video vs. urban video) × 2 (time: before watching video vs. after watching video) repeated measures ANOVAs to investigate whether levels of positive affect and negative affect would be affected by condition and time (Table 1).

First, we found a significant main effect of time on positive affect, such that there was a significant and large decrease in positive affect from pre-test (M = 2.17, SD = 0.87) to post-test (M = 1.84, SD = 0.78), $F(1, 138) = 75.73$, $p < .001$, $\eta_p^2 = .354$. However, we did not observe any significant effect of condition (p = .392) nor of the interaction between condition and time (p = .068; Figure 4).

Figure 4

Box Plot Comparing Pre- and Post-Test Positive Affect in Both Conditions

[3] As frequentist approaches like the one used previously do not supply any evidence for the null hypothesis in the case of non-significant *p*-values (Hoijtink et al., 2019), the Bayesian approach offers a helpful alternative in that it directly compares the null and alternative hypotheses (Morey & Rouder, 2011) via the Bayes factor, a likelihood ratio specifying which hypothesis is more likely to be accurate (Goodman, 1999). Thus, evidence for the null hypothesis may be quantified (Ly et al., 2016). The Bayes factor may be interpreted as being under one of six categories: no evidence, anecdotal, moderate, strong, very strong, or decisive (Lee & Wagenmakers, 2013).

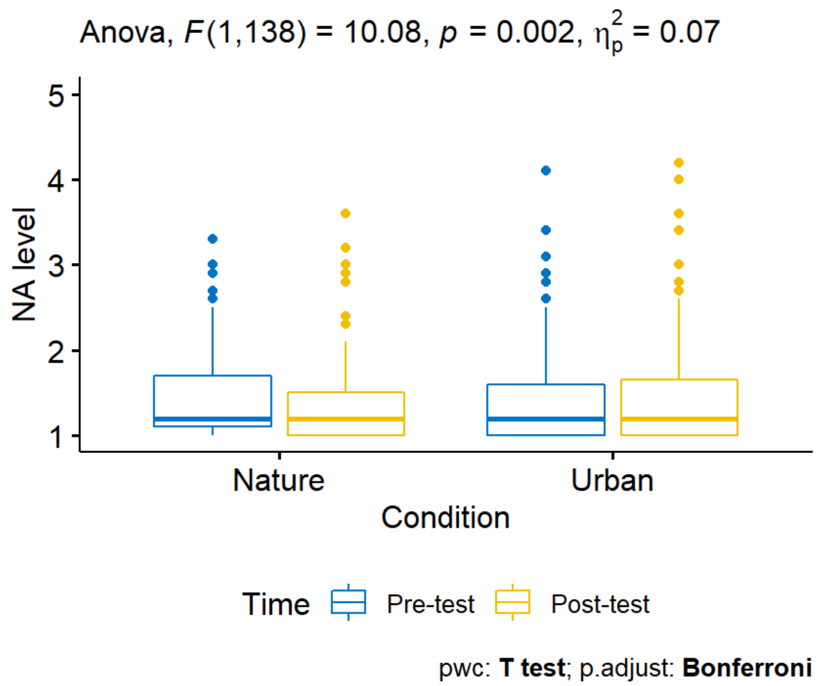


To investigate the support, or lack thereof, for the null hypothesis of the interaction, we conducted Bayesian repeated measures ANOVA. Specifically, we tested the same alternative model—where levels of positive affect was predicted by time, condition, and their interaction—against a null model where positive affect score was only predicted by time and condition (i.e., without the interaction). We found anecdotal evidence for the null hypothesis, BF_{01} = 1.34, implying that the null hypothesis was 1.34 times as likely to be true as the alternative hypothesis. This corroborated our previous findings suggesting that the type of video watched had no significant effect on the difference between pre- and post-test level of positive affect.

Second, we found a significant main effect of time on negative affect, such that there was a significant and small decrease in negative affect from pre-test (M = 1.45, SD = 0.56) to post-test (M = 1.40, SD = 0.55), $F(1, 138) = 5.24$, $p = .024$, $\eta_p^2 = .037$. However, like for positive affect, we did not observe any significant effect of condition ($p = .467$). In contrast to positive affect, we found a significant interaction between time and condition on negative affect, $F(1, 138) = 10.08$, $p = .002$, $\eta_p^2 = .068$ (Figure 5). Hence, we conducted post-hoc pairwise comparisons with Bonferroni corrections, which showed that participants in the nature condition had significantly higher negative affect at pre-test ($M = 1.47$, $SD = 0.56$) as compared to post-test ($M = 1.35$, $SD = 0.49$), $p < .001$, suggesting that watching the nature video significantly reduced negative affect. At the same time, negative affect at pre-test ($M = 1.43$, $SD = 0.57$) and post-test ($M = 1.44$, $SD = 0.60$) in the urban condition did not differ significantly ($p = .561$).

Figure 5

Box Plot Comparing Pre- and Post-test Negative Affect in Both Conditions



To investigate the support for the null hypothesis of the interaction we conducted Bayesian repeated measures ANOVA. Specifically, we tested the same alternative model—where levels of negative affect were predicted by time, condition, and their interaction—against a null model where negative affect score was only predicted by time and condition (i.e., without the interaction). We found that $BF_{01} = 0.05$ (i.e., $BF_{10} = 20.83$), implying that the alternative hypothesis was more than 20 times as likely to be true as the null hypothesis. Again, this finding was consistent with those from our frequentist analyses, suggesting that the type of video watched had a significant effect on the difference between pre- and post-test levels of negative affect.

Discussion

According to attention restoration theory (Kaplan, 1995), nature has a restorative effect on an individual's attentional resources after a mentally fatiguing task. Consistently, existing studies have found that direct exposure to real nature environments have positive effects on performance on tasks that demand executive attention (e.g., Faber Taylor & Kuo, 2009; Gamble et al., 2014; Stenfors et al., 2019; Stevenson et al., 2019; Tennessen & Cimprich, 1995). However, due to previous mixed findings (e.g., Cassarino et al., 2019b; Emfield & Neider, 2014; Johnson et al., 2022), it remains unclear whether virtual nature simulations can serve as a substitute for real nature experienced in the outdoors, in terms of restoring executive attention. The present study sought to re-examine if virtual exposure to nature would restore participants' performance on executive attention. Major methodological improvements were made to increase the sensitivity of the current study to detect the cognitive restoration effect of virtual nature simulations. First, a high-powered fully within-subject experimental approach was employed to increase our statistical power (Charness et al., 2012). Second, we employed complex span task to measure working memory capacity that placed high demand on executive attention (Foster et al., 2015; Kane et al., 2001; McCabe et al., 2010; Unsworth et al., 2009). Third, we employed videos depicting a walk down a forest path and an urban environment in first-person view, instead of pictorial stimuli, to replicate the experiences of nature with relatively higher level of immersion.

Overall, our within-subject experiment did not find any evidence to support the benefit of watching videos with natural scenery on restoration of executive attention. Participants displayed similar levels of working memory capacity in both the nature and urban conditions, suggesting that the nature condition did not lead to restoration effects. Moreover, results from our Bayesian analyses further showed substantial support for the null hypothesis for working memory capacity and positive affect levels, and did not contradict the null hypothesis for negative affect levels. In the pursuit of introducing more available interventions to improve cognitive functions, despite the economic efficiency and convenience of virtual nature simulations, the current results suggest that such virtual nature simulations (e.g., videos with natural scenery) may not be effective substitutes for real nature experienced in the outdoors if the aim is to restore attentional resources.

The null effect found in the current study is consistent with existing studies that have failed to replicate the effect of viewing virtual natural environments on cognitive functions (Cassarino et al., 2019b; Emfield & Neider, 2014; Johnson et al., 2022; Kuziek, 2017). While our current study employed the usage of videos, previous studies that similarly failed to replicate effects on cognitive functions have used a range of virtual simulations, including images and audio recordings. As such, the null effect observed does seem to be consistent regardless of the type of virtual nature simulation used. Moreover, most of these studies recruited non-probability sampling with university students as their samples, which is similar to the current study. Instead, a more plausible explanation of the current null finding would be that nature video may not be a sufficient substitute for the experience of nature in the outdoors. Given that soft fascination, a feeling of being away, extent, and compatibility are necessary components for environments to elicit attention restoration according to attention restoration theory (Kaplan, 1995), our study may suggest that virtual nature simulations—even with the use of videos—may not be able to replicate the experience of nature in the outdoors. For instance, nature videos might generate a limited feeling of fascination and being away in viewers, such that viewers are less likely to be fascinated and are likely to be still aware of the current experimental setting they are in. Due to the limitation of virtual nature simulations, it is plausible that real nature settings are more reliable in restoring attentional resources.

In addition, our exploratory analyses on affect showed the nature video significantly reduced negative affect but not increased positive affect in the current study. The findings only partially support Stress Reduction Theory (Ulrich 1983) and are inconsistent with the Perceptual Fluency Account (Joye & van den Berg, 2011) which predicts higher positive affect after watching stimuli that is easy to process and understand. Thus, it is plausible that the null effect found in the current study is contributed by the lack increment in the positive affect. The current finding suggest that short nature video may not be sufficient to increase positive affect. Our findings are consistent with several recent studies which found that watching nature videos decreases negative affect but does not increase positive affect (Erdinc, 2021; Meuwese et al., 2021).

Of note, there are several limitations of the current study. First, the current study employed a single complex span task (i.e., operation span task). As a result, our finding could be task-specific and may not be generalizable to other tasks measuring executive attention. Given the multidimensional nature of executive functions (Diamond, 2013; Miyake et al., 2000), it is important for future studies to replicate the current study with other executive functions tasks that measure other aspects of executive functions such as task-switching paradigm for task-switching and flanker task for inhibitory control. Furthermore, due to the widespread issue of task impurity in tasks measuring executive attention (Baggetta & Alexander, 2016; Hartanto & Yang, 2020; Miyake et al., 2000), it is also important for future studies to employ more than one working memory task such as n-back task to address issues related to task impurity. Second, it is possible that our participants were not cognitively depleted after the pre-test condition. Thus, it is important for future studies to employ a longer cognitive task in the pre-test condition to ensure that there is room for attentional restoration after the exposure to virtual nature simulations. Third, we are unable to completely dismiss the possibility that our selected stimuli may partly contribute to the null finding. For instance, it is possible that our decision to control for novelty by choosing foreign landscapes may reduce perceptual fluency due to unfamiliarity. Fourth, given the non-probability nature of the current undergraduate sample, the selection bias may limit the generalizability of our current findings, although it is noteworthy that many of the existing studies testing attention restoration with real nature found significant positive effect in undergraduate samples with non-probability sampling (e.g., Berman et al., 2008; Gamble et al., 2014; Tennessen & Cimprich, 1995). Fifth, it is plausible that external confounders or hidden moderators that were unidentified in the current study contributed to the null effect. Lastly, given that the current study was based on a highly built-up urbanized country (Singapore), it is possible that our participants might be generally lower in nature connectedness, which is an important individual difference that can moderate the effect of exposure to nature (Koivisto et al., 2022; Mayer et al., 2009). Thus, findings from the current study may not be generalizable to other regions with different level of nature connectedness. More studies should be conducted to examine the generalizability of the null findings in the current study to other regions.

In summary, the present study showed that viewing videos with natural scenery do not have any effect on working memory capacity in a high-powered pre-registered within-subject experimental study. Consistent with existing studies that failed to replicate the positive cognitive effect of viewing pictures of nature settings (e.g., Cassarino et al., 2019a; Johnson et al., 2022; Neilson et al., 2021), the current study reaffirms this conclusion that virtual nature simulation does not reliably restore attentional resources.

References

Baggetta, P., & Alexander, P. A. (2016). Conceptualization and operationalization of executive function: Executive function. *Mind, Brain, and Education*, *10*(1), 10–33. https://doi.org/10.1111/mbe.12100

Barnes, M. R., Donahue, M. L., Keeler, B. L., Shorb, C. M., Mohtadi, T. Z., & Shelby, L. J. (2019). Characterizing nature and participant experience in studies of nature exposure for positive mental health: An integrative review. *Frontiers in Psychology*, *9*, 2617.

Berman, M. G., Jonides, J., & Kaplan, S. (2008). The cognitive benefits of interacting with nature. *Psychological Science*, *19*(12), 1207–1212. https://doi.org/10.1111/j.1467-9280.2008.02225.x

Berman, M. G., Kross, E., Krpan, K. M., Askren, M. K., Burson, A., Deldin, P. J., Kaplan, S., Sherdell, L., Gotlib, I. H., & Jonides, J. (2012). Interacting with nature improves cognition and affect for individuals with depression. *Journal of Affective Disorders*, *140*(3), 300–305. https://doi.org/10.1016/j.jad.2012.03.012

Berto, R. (2005). Exposure to restorative environments helps restore attentional capacity. *Journal of Environmental Psychology*, *25*(3), 249-259. https://doi.org/10.1016/j.jenvp.2005.07.001

Bourrier, S. C., Berman, M. G., & Enns, J. T. (2018). Cognitive strategies and natural environments interact in influencing executive function. *Frontiers in Psychology*, *9*, 1248. https://doi.org/10.3389/fpsyg.2018.01248

Bratman, G. N., Anderson, C. B., Berman, M. G., Cochran, B., de Vries, S., Flanders, J., Folke, C., Frumkin, H., Gross, J. J., Hartig, T., Kahn, P. H., Kuo, M., Lawler, J. J., Levin, P. S., Lindahl, T., Meyer-Lindenberg, A., Mitchell, R., Ouyang, Z., Roe, J., … Daily, G. C. (2019). Nature and mental health: An ecosystem service perspective. *Science Advances*, *5*(7), eaax0903. https://doi.org/10.1126/sciadv.aax0903

Bratman, G. N., Daily, G. C., Levy, B. J., & Gross, J. J. (2015). The benefits of nature experience: Improved affect and cognition. *Landscape and Urban Planning*, *138*, 41–50. https://doi.org/10.1016/j.landurbplan.2015.02.005

Bratman, G. N., Hamilton, J. P., & Daily, G. C. (2012). The impacts of nature experience on human cognitive function and mental health: Nature experience, cognitive function, and mental health. *Annals of the New York Academy of Sciences*, *1249*(1), 118–136. https://doi.org/10.1111/j.1749-6632.2011.06400.x

Cassarino, M., Maisto, M., Esposito, Y., Guerrero, D., Chan, J. S., & Setti, A. (2019). Testing attention restoration in a virtual reality driving simulator. *Frontiers in Psychology*, *10*, 250. https://doi.org/10.3389/fpsyg.2019.00250

Cassarino, M., Tuohy, I. C., & Setti, A. (2019). Sometimes nature doesn't work: Absence of attention restoration in older adults exposed to environmental scenes. *Experimental Aging Research*, *45*(4), 372–385. https://doi.org/10.1080/0361073X.2019.1627497

Charness, G., Gneezy, U., & Kuhn, M. A. (2012). Experimental methods: Between-subject and within-subject design. *Journal of Economic Behavior & Organization*, *81*(1), 1–8. https://doi.org/10.1016/j.jebo.2011.08.009

Conway, A. R. A., Kane, M. J., & Engle, R. W. (2003). Working memory capacity and its relation to general intelligence. *Trends in Cognitive Sciences*, *7*(12), 547–552. https://doi.org/10.1016/j.tics.2003.10.005

Diamond, A. (2013). Executive functions. *Annual Review of Psychology*, *64*, 135. https://doi.org/10.1146/annurev-psych-113011-143750

Emfield, A. G., & Neider, M. B. (2014). Evaluating visual and auditory contributions to the cognitive restoration effect. *Frontiers in Psychology*, *5*. https://doi.org/10.3389/fpsyg.2014.00548

Erdinc, H. (2021). *Watching a nature video improves negative affect and stress but does not change positive affect* [Master Thesis] University of Glasgow.

Faber Taylor, A., & Kuo, F. E. (2009). Children with attention deficits concentrate better after walk in the park. *Journal of Attention Disorders*, *12*(5), 402–409. https://doi.org/10.1177/1087054708323000

Faul, F., Erdfelder, E., Lang, A.-G., & Buchner, A. (2007). G*Power 3: A flexible statistical power analysis program for the social, behavioral, and biomedical sciences. *Behavior Research Methods*, *39*(2), 175–191. https://doi.org/10.3758/BF03193146

Foster, J. L., Harrison, T. L., Hicks, K. L., Draheim, C., Redick, T. S., & Engle, R. W. (2017). Do the effects of working memory training depend on baseline ability level? *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *43*(11), 1677-1689. https://doi.org/10.1037/xlm0000426

Foster, J. L., Shipstead, Z., Harrison, T. L., Hicks, K. L., Redick, T. S., & Engle, R. W. (2015). Shortened complex span tasks can reliably measure working memory capacity. *Memory & Cognition, 43*, 226 – 236. https://doi.org/10.3758/s13421-014-0461-7

Frigione, I., Massetti, G., Girondini, M., Etzi, R., Scurati, G. W., Ferrise, F., Chirico, A., Gaggioli, A., & Gallace, A. (2022). An exploratory study on the effect of virtual environments on cognitive performances and psychophysiological responses. *Cyberpsychology, Behavior, and Social Networking*, *25*(10), 666 – 671. https://doi.org/ 10.1089/cyber.2021.0162

Gallant, S. N. (2016). Mindfulness meditation practice and executive functioning: Breaking down the benefit. *Consciousness and Cognition*, *40*, 116-130. https://doi.org/10.1016/j.concog.2016.01.005

Gamble, K. R., Howard, J. H., & Howard, D. V. (2014). Not just scenery: Viewing nature pictures improves executive attention in older adults. *Experimental Aging Research*, *40*(5), 513–530. https://doi.org/10.1080/0361073X.2014.956618

Gao, Z., Ye, T., Shen, M., & Perry, A. (2016). Working memory capacity of biological movements predicts empathy traits. *Psychonomic Bulletin & Review*, *23*(2), 468–475. https://doi.org/10.3758/s13423-015-0896-2

Gathercole, S. E., Pickering, S. J., Knight, C., & Stegmann, Z. (2004). Working memory skills and educational attainment: Evidence from national curriculum assessments at 7 and 14 years of age. *Applied Cognitive Psychology, 18*(1), 1-16. https://doi.org/10.1002/acp.934

Gillis, K., & Gatersleben, B. (2015). A review of psychological literature on the health and wellbeing benefits of biophilic design. *Buildings, 5*(3), 948 – 963. https://doi.org/10.3390/buildings5030948

Goh, A. Y., Chia, S. M., Majeed, N. M., Chen, N. R., & Hartanto, A. (2023). Untangling the additive and multiplicative relations between natural scenery exposure and human – animal interaction on affective well-being: Evidence from daily diary studies. *Sustainability, 15*(4), 2910. https://doi.org/10.3390/su15042910

Goodman, S. N. (1999). Toward evidence-based medical statistics. 2: The Bayes factor. *Annals of Internal Medicine, 130*(12), 1005 – 1013. https://doi.org/10.7326/0003-4819-130-12-199906150-00019

Harrison, T. L., Shipstead, Z., Hicks, K. L., Hambrick, D. Z., Redick, T. S., & Engle, R. W. (2013). Working memory training may increase working memory capacity but not fluid intelligence. *Psychological Science, 24*(12), 2409 – 2419. https://doi.org/10.1177/0956797613492984

Hartanto, A., Ong, N. C. H., Ng, W. Q., & Majeed, N. M. (2020). The effect of state gratitude on cognitive flexibility: A within-subject experimental approach. *Brain Sciences, 10*(7), 413. https://doi.org/10.3390/brainsci10070413

Hartanto, A., Teo, N. L. A., Lua, V. Y. Q., Tay, K. J. Y., Chen, N. R. Y., & Majeed, N. M. (2023). Pre-registration and data for: "*Does watching videos with natural scenery restore attentional resources? A critical examination through a pre-registered within-subject experiment. https://researchbox.org/861*

Hartanto, A., & Yang, H. (2020). The role of bilingual interactional contexts in predicting interindividual variability in executive functions: A latent variable analysis. *Journal of Experimental Psychology: General*, *149*(4), 609–633. https://doi.org/10.1037/xge0000672

Hartig, T., Evans, G. W., Jamner, L. D., Davis, D. S., & Garling, T. (2003). Tracking restoration in natural and urban field settings. J*ournal of Environmental Psychology, 23*(2), 109 – 123.

Hoijtink, H., Mulder, J., van Lissa, C., & Gu, X. (2019). A tutorial on testing hypotheses using the Bayes factor. *Psychological Methods, 24*(5), 539 – 556. https://doi.org/10.1037/met0000201

Houlden, V., Jani, A., & Hong, A. (2021). Is biodiversity of greenspace important for human health and wellbeing? A bibliometric analysis and systematic literature review. *Urban Forestry & Urban Greening*, *66*, 127385. https://doi.org/10.1016/j.ufug.2021.127385

Hunt, J. T., Howell, A. J., & Passmore, H. A. (2020). In vivo nature exposure as a positive psychological intervention: A review of the impact of nature interventions on wellbeing. In E. Brymer, M. Rogerson, & J. Barton (Eds.), *Nature and health: Physical activity in nature* (pp. 160–174). Routledge.

Huynh, Q., Craig, W., Janssen, I., & Pickett, W. (2013). Exposure to public natural space as a protective factor for emotional well-being among young people in Canada. *BMC Public Health*, *13*(1), 407. https://doi.org/10.1186/1471-2458-13-407

Jamrozik, A., Clements, N., Hasan, S. S., Zhao, J., Zhang, R., Campanella, C., ... & Bauer, B. (2019). Access to daylight and view in an office improves cognitive performance and satisfaction and reduces eyestrain: A controlled crossover study. *Building and Environment*, *165*, *106379.* https://doi.org/10.1016/j.buildenv.2019.106379

JASP Team (2022). JASP (0.16.3). https://jasp-stats.org/2022/06/16/introducing-jasp-0-16-3-quality-control-glms-bayesian-state-space-models-improvements-to-bayesian-anova-and-more/

Johnson, J. A., Hansen, B. E., Funk, E. L., Elezovic, F. L., & Finley, J.-C. A. (2021). Conceptual replication study and meta-analysis suggest simulated nature does not reliably restore pure executive attention measured by the attention network task. *Journal of Environmental Psychology*, *78*, 101709–101709. https://doi.org/10.1016/j.jenvp.2021.101709

Johnson, K. A., Pontvianne, A., Ly, V., Jin, R., Januar, J. H., Machida, K., Sargent, L. D., Lee, K. E., Williams, N. S. G., & Williams, K. J. H. (2022). Water and meadow views both afford perceived but not performance-based attention restoration: Results from two experimental studies. *Frontiers in Psychology*, *13*, 809629. https://doi.org/10.3389/fpsyg.2022.809629

Joye, Y., & Van den Berg, A. (2011). Is love for green in our genes? A critical analysis of evolutionary assumptions in restorative environments research. *Urban Forestry & Urban Greening*, *10*(4), 261-268. https://doi.org/10.1016/j.ufug.2011.07.004

Kane, M. J., Bleckley, M. K., Conway, A. R. A., & Engle, R. W. (2001). A controlled-attention view of working-memory capacity. *Journal of Experimental Psychology: General*, *130*(2), 169–183. https://doi.org/10.1037/0096-3445.130.2.169

Kaplan, R. (2001). The nature of the view from home: Psychological benefits. *Environment and Behavior*, *33*(4), 507–542. https://doi.org/10.1177/00139160121973115

Kaplan, S. (1995). The restorative benefits of nature: Toward an integrative framework. *Journal of Environmental Psychology*, *15*(3), 169–182. https://doi.org/10.1016/0272-4944(95)90001-2

Kaplan, S., & Berman, M. G. (2010). Directed attention as a common resource for executive functioning and self-regulation. *Perspectives on Psychological Science*, *5*(1), 43–57. https://doi.org/10.1177/1745691609356784

Kassambara, A. (2021). *Rstatix: Pipe-friendly framework for basic statistical tests* (0.7.0) [R]. https://cran.r-project.org/web/packages/rstatix/index.html

Koivisto, M., Jalava, E., Kuusisto, L., Railo, H., & Grassini, S. (2022). Top-down processing and nature connectedness predict psychological and physiological effects of nature. *Environment and Behavior*, *54*(5), 917–945. https://doi.org/10.1177/00139165221107535

Kuziek, J. W. (2017). *Cognitive markers of attentional restoration while viewing natural and urban environments* [Master Thesis]. University of Alberta. https://doi.org/10.7939/R3HD7P65P

La Pointe, L. B., & Engle, R. W. (1990). Simple and complex word spans as measures of working memory capacity. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *16*(6), 1118–1133. https://doi.org/10.1037/0278-7393.16.6.1118

Lee, M. D., & Wagenmakers, E.-J. (2013). Bayesian cognitive modeling: A practical course. Cambridge University Press. https://doi.org/10.1017/CBO9781139087759

Lemonaki, R., Xanthopoulou, D., Bardos, A. N., Karademas, E. C., & Simos, P. G. (2021). Burnout and job performance: A two-wave study on the mediating role of employee cognitive functioning. *European Journal of Work and Organizational Psychology*, *30*(5), 692–704. https://doi.org/10.1080/1359432X.2021.1892818

Li, H., Dong, W., Wang, Z., Chen, N., Wu, J., Wang, G., & Jiang, T. (2021). Effect of a virtual reality-based restorative environment on the emotional and cognitive recovery of individuals with mild-to-moderate anxiety and depression. *International Journal of Environmental Research and Public Health*, *18*(17), 9053. https://doi.org/10.3390/ijerph18179053

Ly, A., Verhagen, J., & Wagenmakers, E. J. (2016). Harold Jeffreys's default Bayes factor hypothesis tests: Explanation, extension, and application in psychology. *Journal of Mathematical Psychology, 72*, 19 – 32. https://doi.org/10.1016/j.jmp.2015.06.004

Mayer, F. S., Frantz, C. M., Bruehlman-Senecal, E., & Dolliver, K. (2009). Why is nature beneficial?: The role of connectedness to nature. *Environment and Behavior*, *41*(5), 607–643. https://doi.org/10.1177/0013916508319745

McAllister, E., Bhullar, N., & Schutte, N. S. (2017). Into the woods or a stroll in the park: How virtual contact with nature impacts positive and negative affect. I*nternational Journal of Environmental Research and Public Health, 14*(7), 786. https://doi.org/10.3390/ijerph14070786

McCabe, D. P., Roediger, H. L., McDaniel, M. A., Balota, D. A., & Hambrick, D. Z. (2010). The relationship between working memory capacity and executive functioning: Evidence for a common executive attention construct. *Neuropsychology*, *24*(2), 222–243. https://doi.org/10.1037/a0017619

Meuwese, D., Dijkstra, K., Maas, J., & Koole, S. L. (2021). Beating the blues by viewing Green: Depressive symptoms predict greater restoration from stress and negative affect after viewing a nature video. *Journal of Environmental Psychology*, *75*, 101594. https://doi.org/10.1016/j.jenvp.2021.101594

Miyake, A., Friedman, N. P., Emerson, M. J., Witzki, A. H., Howerter, A., & Wager, T. D. (2000). The unity and diversity of executive functions and their contributions to complex "frontal lobe" tasks: A latent variable analysis. *Cognitive Psychology*, *41*(1), 49–100. https://doi.org/10.1006/cogp.1999.0734

Moore, A. B., Clark, B. A., & Kane, M. J. (2008). Who shalt not kill? Individual differences in working memory capacity, executive control, and moral judgment. *Psychological Science*, *19*(6), 549–557. https://doi.org/10.1111/j.1467-9280.2008.02122.x

Morey, R. D., & Rouder, J. N. (2011). Bayes factor approaches for testing interval null hypotheses. *Psychological Methods*, *16*(4), 406 – 419. https://doi.org/10.1037/a0024377

Neilson, B. N., Craig, C. M., Curiel, R. Y., & Klein, M. I. (2021). Restoring attentional resources with nature: A replication study of Berto's (2005) paradigm including commentary from Dr. Rita Berto. *Human Factors: The Journal of the Human Factors and Ergonomics Society*, *63*(6), 1046–1060. https://doi.org/10.1177/0018720820909287

Palanica, A., Lyons, A., Cooper, M., Lee, A., & Fossat, Y. (2019). A comparison of nature and urban environments on creative thinking across different levels of reality. *Journal of Environmental Psychology*, *63*, 44-51. https://doi.org/10.1016/j.jenvp.2019.04.006

Pasanen, T., Johnson, K., Lee, K., & Korpela, K. (2018). Can nature walks with psychological tasks improve mood, self-reported restoration, and sustained attention? Results from two experimental field studies. *Frontiers in Psychology*, *9*, 2057. https://doi.org/10.3389/fpsyg.2018.02057

Pilotti, M., Klein, E., Golem, D., Piepenbrink, E., & Kaplan, K. (2015). Is viewing a nature video after work restorative? Effects on blood pressure, task performance, and long-term memory. *Environment and Behavior, 47*(9), 947–969. https://doi.org/10.1177/0013916514533187

Pimentel, D., & Pimentel, M. (2003). World population, food, natural resources, and survival. *World Futures*, *59*(3–4), 145–167. https://doi.org/10.1080/02604020310124

Pollard, M. A., & Courage, M. L. (2017). Working memory capacity predicts effective multitasking. *Computers in Human Behavior*, *76*, 450–462. https://doi.org/10.1016/j.chb.2017.08.008

Pritchard, A., Richardson, M., Sheffield, D., & McEwan, K. (2020). The relationship between nature connectedness and eudaimonic well-being: A meta-analysis. *Journal of Happiness Studies: An Interdisciplinary Forum on Subjective Well-Being*, *21*(3), 1145–1167. psyh. https://doi.org/10.1007/s10902-019-00118-6

Quek, F., Majeed, N., Kothari, M., Lua, V., Ong, H., & Hartanto, A. (2021). Brief mindfulness breathing exercises and working memory capacity: Findings from two experimental approaches. *Brain Sciences*, *11*(2), 175. https://doi.org/10.3390/brainsci11020175

R Core Team. (2020). *R: A language and environment for statistical computing.* (3.6.3). R Foundation for Statistical Computing. https://www.R-project.org/

Redick, T. S., Broadway, J. M., Meier, M. E., Kuriakose, P. S., Unsworth, N., Kane, M. J., & Engle, R. W. (2012). Measuring working memory capacity with automated complex span tasks. *European Journal of Psychological Assessment*, *28*(3), 164-171. https://doi.org/10.1027/1015-5759/a000123

Revelle, W. (2021). *psych: Procedures for psychological, psychometric, and personality research* (2.1.6) [R]. Northwestern University.

Schertz, K. E., & Berman, M. G. (2019). Understanding nature and its cognitive benefits. *Current Directions in Psychological Science*, *28*(5), 496–502. https://doi.org/10.1177/0963721419854100

Stenfors, C. U. D., Van Hedger, S. C., Schertz, K. E., Meyer, F. A. C., Smith, K. E. L., Norman, G. J., Bourrier, S. C., Enns, J. T., Kardan, O., Jonides, J., & Berman, M. G. (2019). Positive effects of nature on cognitive performance across multiple experiments: Test order but not affect modulates the cognitive effects. *Frontiers in Psychology*, *10*, 1413. https://doi.org/10.3389/fpsyg.2019.01413

Stevenson, M. P., Dewhurst, R., Schilhab, T., & Bentsen, P. (2019). Cognitive restoration in children following exposure to nature: Evidence from the attention network task and mobile eye tracking. *Frontiers in Psychology*, *10*, 42. https://doi.org/10.3389/fpsyg.2019.00042

Storbeck, J., & Maswood, R. (2016). Happiness increases verbal and spatial working memory capacity where sadness does not: Emotion, working memory and executive control. *Cognition and Emotion*, *30*(5), 925-938. https://doi.org/10.1080/02699931.2015.1034091

Tennessen, C. M., & Cimprich, B. (1995). Views to nature: Effects on attention. *Journal of Environmental Psychology*, *15*(1), 77–85. https://doi.org/10.1016/0272-4944(95)90016-0

Ulrich, R. S. (1983). *Aesthetic and affective response to natural environment*. In I., Altman, J. F. Wohlwill, (Eds.), Behavior and the natural environment (pp. 85–125). Springer, US.

Unsworth, N., Redick, T. S., Heitz, R. P., Broadway, J. M., & Engle, R. W. (2009). Complex working memory span tasks and higher-order cognition: A latent-variable analysis of the relationship between processing and storage. *Memory*, *17*(6), 635–654. https://doi.org/10.1080/09658210902998047

Van Hedger, S. C., Nusbaum, H. C., Clohisy, L., Jaeggi, S. M., Buschkuehl, M., & Berman, M. G. (2019). Of cricket chirps and car horns: The effect of nature sounds on cognitive performance. *Psychonomic Bulletin & Review*, *26*(2), 522-530. https://doi.org/10.3758/s13423-018-1539-1

Valtchanov, D., Barton, K. R., & Ellard, C. (2010). Restorative effects of virtual nature settings. *Cyberpsychology, Behavior, and Social Networking*, *13*(5), 503-512. https://doi.org/10.1089/cyber.2009.0308

Vaughan, R. S., & Laborde, S. (2021). Attention, working-memory control, working-memory capacity, and sport performance: The moderating role of athletic expertise. *European Journal of Sport Science*, *21*(2), 240–249. https://doi.org/10.1080/17461391.2020.1739143

Weeland, J., Moens, M. A., Beute, F., Assink, M., Staaks, J. P. C., & Overbeek, G. (2019). A dose of nature: Two three-level meta-analyses of the beneficial effects of exposure to nature on children’s self-regulation. *Journal of Environmental Psychology*, *65*. psyh. https://doi.org/10.1016/j.jenvp.2019.101326

White, M. P., Alcock, I., Grellier, J., Wheeler, B. W., Hartig, T., Warber, S. L., Bone, A., Depledge, M. H., & Fleming, L. E. (2019). Spending at least 120 minutes a week in nature is associated with good health and wellbeing. *Scientific Reports*, *9*(1), 7730. https://doi.org/10.1038/s41598-019-44097-3

White, M. P., Pahl, S., Wheeler, B. W., Depledge, M. H., & Fleming, L. E. (2017). Natural environments and subjective wellbeing: Different types of exposure are associated with different aspects of wellbeing. *Health & Place*, *45*, 77–84.

Wickham, H. (2016). *ggplot2: Elegant Graphics for Data Analysis* (2nd ed. 2016). Springer International Publishing : Imprint: Springer. https://doi.org/10.1007/978-3-319-24277-4

Yang, H., Yang, S., & Isen, A. M. (2013). Positive affect improves working memory: Implications for controlled cognitive processing. *Cognition & Emotion*, *27*(3), 474-482. https://doi.org/10.1080/02699931.2012.713325

Yeung, Y.-Y., & Yu, C.-P. (2022). Cognitive-emotional benefits of weekly exposure to nature: A Taiwanese study on young adults. *Sustainability*, *14*(13), 7828. https://doi.org/10.3390/su14137828