INVESTIGATING WORKING MEMORY CAPACITY IN AN ONLINE NATURE INTERVENTION

by

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ABSTRACT

Viewing natural stimuli has shown to have beneficial effects on cognition. However, for those in urban areas, nature may not be as accessible. An online intervention may allow them to receive such cognitive benefits. However, specific cognitive processes that may benefit from nature are still not well understood. This study aimed to investigate which cognitive processes could benefit from an online nature intervention. Two hundred and nineteen participants were recruited from Montana State University and completed two tasks that measured either Working Memory Capacity, attentional control, or memory. Within each task, 40 nature images and 40 urban images were randomly presented before each experimental block in the two tasks. Results revealed higher performance after viewing nature images compared to urban images across attentional control tasks but not for Working Memory Capacity or memory. When controlling for preference for natural settings and nature images, the effect became marginal for attentional control tasks. Exploratory analyses revealed that this effect of nature became nonsignificant when controlling across dimensions of fascination and mystery. These results indicate a small, but significant, benefit of viewing natural settings for attentional control, an essential component of Working Memory Capacity. Future research should investigate if benefits increase with longer or more comprehensive interaction with nature, individual differences in the degree of benefits nature can provide, and characteristics that natural settings possess which may increase attentional benefits.

INTRODUCTION

Attentional fatigue can come from work, cognitive activities, and stressful situations, but nature is one context that restores attention, according to Kaplan's Attention Restoration Theory (ART, 1995). However, access to nature for these unspecified cognitive benefits may be limited. Because of this, studies comparing simple exposure to nature versus urban stimuli have shown that exposure to natural stimuli benefits performance in attentional tasks (Amicone et al., 2018; Berman, Jonides, & Kaplan, 2008; Berto, 2005; Johnson et al., 2019). However, due to mixed results, the specific cognitive processes that receive benefits from natural stimuli still need specification. Understanding the particular cognitive processes that show increased performance after exposure to natural stimuli can help researchers understand the mechanisms of nature-based benefits.

Unfortunately, many individuals may not have the financial means or proximal accessibility to participate in outdoor activities in nature. By creating an online nature intervention and understanding which cognitive processes are benefited when exposed to natural digital stimuli, our investigation can determine if digital images can provide benefits for those who have limited access to nature and, more specifically, target the intervention to those who struggle with the specific cognitive process that nature is found to help improve.

Mechanisms of Attention Restoration Theory

ART has four components through which nature presumably restores attention: *fascination*, *extent*, *compatibility*, and *being away* (Kaplan, 1995). The first of these, *fascination*, is the involuntary interest in the natural environment. Extent refers to how immersive and coherent the nature stimuli. Compatibility refers to the degree to which the activity of being in nature aligns with one's goals. Finally, being away refers to people's sense of distance from their daily routine and environment.

To test the effects of fascination, Szolosi et al. (2014) normalized images of nature into groups of high and low fascination and mystery to examine potential benefits of these characteristics. Specifically, they asked participants to rate 80 images of nature on both mystery and fascination. For mystery, they asked to what extent the setting has more to be seen if going deeper into the scene. For fascination, they used the fascination subscale of the Perceived Restorative Scale (Hartig et al. 1996). They then asked participants to study these nature images for 1, 5, or 10 seconds for a later Recognition Memory Task. Images that were more mysterious had a recognition benefit relative to less mysterious items, which was mediated by fascination. Specifically, mystery was positively related to fascination and both mystery and fascination were positively related to recognition performance. They also found an indirect effect of mystery to recognition performance, mediated by fascination. In addition, they found that recognition benefits for high fascination/more mysterious items increased across longer viewing times, where the benefit was present at one second of viewing each image, and increased at the 5 and 10 second viewings, which did not differ. This suggests that only 5-10 seconds of viewing time might provide an adequate nature experience to receive cognitive benefits. This work suggests that more fascinating images may be effective for a digital nature intervention to improve recognition, as long as the images are presented for at least 5 seconds.

In terms of the compatibility component of ART, many studies have found that being in nature is indeed typically seen as compatible with the goal of emotional and cognitive restoration

(Beute & de Kort, 2013; Dzhambov et al., 2019; Meidenbauer et al., 2019; Scopelliti et al., 2019; Scopelliti & Vittoria, 2004). Thus, people believe that natural environments are restorative. As a result, it may be that nature-based improvements in performance are due to a placebo effect, in which people expect to perform better after nature, especially if such improvements are based only on self-report. Related to this, natural stimuli, even sounds, that are rated high on the Perceived Restorativeness Scale are also rated as highly preferable by participants (Purcell et al., 2001; Van Hedger et al., 2018). It is possible that this preference is partly due to a belief in the restorative power of nature. Alternatively, preferred stimuli might improve performance through some other mechanism, such as improving mood or guiding participants to focus more attention on, and/or interest in, such pictures (Van Hedger et al., 2018; Purcell et al., 2001; Ulrich et al., 1991).

Given the Szolosi et al. (2014) study discussed above, the most useful online intervention would likely have highly fascinating images shown for at least 5 seconds. In addition, in order to ensure the results are not due to simple preference differences, it would also be useful when examining the effectiveness of this intervention to compare preferences for nature and urban images.

Viewing Natural Versus Urban Stimuli: Evidence from Eye-Tracking

Evidence from eye-tracking studies reveals that nature images may, in fact, be restorative and such restoration might be due to capturing more interest and involving less cognitive effort involved during viewing. Franěk and colleagues (2018) demonstrated that natural scenes were indeed perceived as more restorative compared to urban scenes. Moreover, natural scenes were also associated with fewer eye fixations, longer fixation durations, and less travel distance during saccades. In previous studies, such eye fixation and movement patterns have been obtained when participants navigate less complex, compared to more complex, websites and have been suggested to indicate less effortful concentration (Ehmke & Wilson, 2007). In a related study, Martínez-Soto et al. (2019) found similar eye fixation differences between nature and urban images, but also reported that natural environments elicited larger pupil diameters. Although pupil size is often used as a marker of greater effort, it can also demonstrate greater interest value of visual stimuli (Hess & Polt, 1960). Overall, this pattern of fewer, but longer, fixations, less distance during saccades, and larger pupil diameter when viewing nature images suggests that natural settings might require less cognitive effort to process, but still capture more interest compared to urban settings. This, in turn, indicates why fascination may be an especially important mechanism for restoring attention. Specifically, nature's inherently greater interest value could grasp attention, but do so in a less effortful way that allows cognitive processes to restore.

What Specific Cognitive Processes does Nature Benefit?

ART states that nature benefits directed attention. As such, in the context of ART, Kaplan and colleagues have defined directed attention as limited and effortful, focusing on the task rather than distraction, and utilizing other cognitive processes (Kaplan, 1995; Kaplan & Berman, 2010; Kaplan & Kaplan 1989). Stevenson et al. (2018) extended this definition by adding that cognitive *demand*, the *direction* of attentional focus, and locus of *distraction* are helpful constructs to help categorize specific tasks that may benefit from natural exposure. Given these suggestions, an ideal task that should benefit from nature would involve directing attention, either internally or externally, while suppressing salient distractions under high cognitive load.

Stevenson et al.’s (2018) literature review of studies that investigate the cognitive benefits of nature found that cognitive flexibility and working memory capacity (WMC) have most reliably benefited from natural environments and, to a less reliable degree, so has attentional control. In the literature review, they analyzed 42 studies that investigated cognitive flexibility, WMC, attentional control, visual attention, vigilance, impulse control, processing speed, and other emerging domains of cognition in the ART literature (Stevenson, et al., 2018). In the review, they found three different cognitive flexibility outcome measures and seven different working memory measures that benefited from exposure to various natural environments or stimuli. Both attentional control and WMC meet the criteria of requiring a high cognitive load and directing attention to a task in the face of distraction. Interestingly, experimentally-induced attentional fatigue moderated the relationship between natural stimuli and WMC, such that those who were fatigued received greater restoration benefits from nature. This is consistent with nature providing restorative benefits. However, experimentally-induced attention fatigue was not a moderator for cognitive flexibility.

A potential problem with Stevenson et al.’s (2018) review, however, is that they treated each cognitive process (e.g., WMC, attentional control, visual attention, vigilance, impulse control, etc…) as capturing separate abilities, but all tasks involve multiple abilities (Jacoby, 1991) and there is likely much overlap in the underlying processes involved in all these tasks. For instance, WMC is the ability to maintain limited information in the face of distraction. However, WMC is not a unitary construct and is not independent from attentional control, as attentional control is considered the driving factor of individual differences in WMC (Engle, 2002). In fact, Shipstead et al. (2014) and Unsworth et al. (2014) demonstrated that there are three main components of WMC: Primary memory, secondary memory, and attentional control. Primary memory is the size of a person's attentional focus to allow binding of relevant information in WMC. Secondary memory enables retrieving goal-relevant information not maintained in primary memory. Attentional control is the ability to select the task-relevant information to bind and ignore task-irrelevant information. Primary memory keeps important information active, including the task goal. Such primary memory maintenance is guided by attentional control by keeping out distractions while focusing attention on task-relevant information. If such task-related information is forgotten, secondary memory is critical for retrieving this information from long-term memory. As demonstrated by Shipstead et al. and Unsworth et al., performance on WMC tasks is based on all three of these cognitive abilities.

Given the term "attention" in ART, one might predict that attentional control would be the component most affected by exposure to nature. However, in Stevenson et al.'s (2018) literature review, the ten outcome measures analyzed for attentional control had mixed results with various moderators. The beneficial effect held when taking into account moderators of 1) whether or not the participants were cognitively fatigued and 2) real versus virtual nature stimuli. However, when only examining studies that have a pre-test/post-test design, the benefits of viewing natural stimuli disappeared. Therefore, random assignment may not have been successful in the other studies that did not have a pre-test measure of performance, potentially confounding the results with individual differences. Thus, it is unclear whether nature actually benefits attentional control.

There are at least two alternative explanations for weak nature-based benefits for attentional control tasks. First, many of the outcome measures used to measure attentional control use reaction time difference scores as the dependent measure. Such measures typically have low reliability, preventing correlations with other measures (Draheim et al., 2019). As a result, Draheim and colleagues recommend avoiding this problem and improving attentional control measures by using accuracy-based measures instead. Alternatively, another possibility is that any potential benefit that nature provides affects memory, not attentional control. Thus, further investigation using more reliable measures of attentional control are needed, as is comparing nature's potential effects on the other two components of WMC: Primary memory and secondary memory.

Online Medium for Nature Intervention

Investigating the effectiveness of an online nature intervention requires using nature images previously shown to be effective and being able to measure WMC, along with its three components, online. Investigations on traditional WMC tasks online reveal that they can indeed be effectively administered online without participants cheating, but only if researchers avoid using to-be-remembered stimuli that would be easy to write down such as numbers or letters (Hicks et al., 2016). The same logic applies to primary memory, secondary memory, and attentional control tasks as well.

The possibility of measuring cognition online and providing a nature-based intervention might be more important for those who live in urban areas. When comparing test scores from fifth graders living in urban and rural neighborhoods, Tallis et al. (2018) found that test scores correlated with the amount of tree and shrub coverage around the school for children in urban environments, but not for children in rural neighborhoods. This suggests that those who have limited access would benefit most from nature interventions.

Current Study

The purpose of this study was to determine which components of WMC could benefit from an online nature intervention. The highly fascinating images from Szolosi et al. (2014) and the urban images from Berman et al. (2008) were used to compare typical urban environments to highly fascinating natural environments. I chose to use two tasks for each construct to measure WMC, primary memory, secondary memory, and attentional control. Using multiple tasks per construct helps minimize measurement error due to task-specific abilities and therefore increases confidence that nature is benefiting the underlying construct of interest.

Which cognitive constructs benefit from viewing natural stimuli may differ from what is expected according to ART. As predicted when considering ART, attentional control tasks should have higher performance in nature compared to urban trials. However, Stevenson et al. (2018) found less reliable evidence for benefits to attentional control compared to benefits for WMC across studies. Given that attentional control is a component of WMC, it would be expected that attentional control would be benefited more according to ART, however, Stevenson's results suggest that either WMC is most likely to receive the greatest benefits from nature or that memory components of WMC are driving the beneficial effect of nature. Therefore, there is a possibility that primary memory, secondary memory, or both may receive the greatest effects from nature.

This study allows testing for the impact of nature on all three components of WMC separately and combined to determine which component is receiving the greatest benefits from nature. If attentional control has the greatest benefit in nature compared to urban trials this would mean that Stevenson et al.'s findings for WMC were driven by the attentional control component of WMC and the findings for attentional control suffered due to each task not correlating with one another (Draheim et al., 2019). However, if the memory components are most affected by nature, this would be the driving component for the benefits of nature on WMC. Finally, if the greatest effects are in WMC, like in Stevenson et al.'s literature review, this would indicate that benefits of nature come from benefits to attention and memory components.

In addition to testing which WMC component benefits from exposure to natural stimuli, I included a follow-up analysis to determine if preference could account for any such nature-based benefit and whether such benefit is related to specific characteristics of the stimuli. Preference may affect the cognitive benefits of nature if people already believe that nature benefits cognition. Also, exploratory analyses were conducted to determine if mechanisms of fascination and mystery may control for this beneficial effect. Fascination and mystery were characteristics that were specifically chosen to make digital nature more likely to benefit cognition, so controlling for these should account for the benefits seen to any construct unless there are other mechanisms, such as preference, that still make nature effective at benefiting cognition.

METHODS

Participants

In accord with Simmons, Nelson, and Simonsohn (2011), I report how I determined the desired sample size, all data exclusions, all manipulations, and all measures in the study. Two hundred and nineteen participants between the ages of 18-55 were recruited from the Montana State University Subject Pool for credit in an introductory psychology course or extra credit in higher-level psychology courses (M_{age} = 20.46 SD_{age} = 4.66, 89 male, 113 female, 3 other, 41 invalid responses[1]). Using G*Power, I determined that 67 participants would be needed for each condition of the experiment to reach 80% power by conducting a post-hoc t-test analysis on a recent study investigating how natural environments affect visuospatial working memory performance (González-Espinar, et al., *under review*). For this reason, I aimed to run at least seventy participants in each group, with participants randomly assigned to each group. In the end, seventy-four participants completed the WMC tasks, seventy-five completed the attentional control tasks, and seventy completed the memory tasks.

Procedure

Participants clicked a link in which a Qualtrics survey provided them with informed consent. If participants chose to participate in the study, they were then given a download link for either the WMC, attentional control, or primary and secondary memory tasks. Each task was

[1] These invalid responses were due to glitches in the program. These glitches may have been due to the processing power of the computer the participant used as it was not a programming error.

modified to present forty urban images (Berman, 2008) and forty high fascination nature images (Szolosi et al., 2014) for 10 seconds before each block of trials. Within each set of tasks, attention checks were used to make sure participants were giving proper effort for each task. As described in Maniaci and Rogge (2014), these attention checks were a series of questions that were similar to questions asked towards the beginning and end of the task. For example, participants rated the degree to which they agree with the statement "In general… I am a very energetic person" and later "In general… I have a lot of energy" on a 5-point scale. Given how similar these questions are, their answers should be the same from one point in the task to the next if they were paying attention. For each point of difference between both questions, they received 1 point of a failed attention check. There were six attention check pairs, and if participants scored more than 7 points on failed attention checks, they were excluded from the analysis. All participants passed the attention checks, and so were included in the analysis. At the end of the study demographics of age, gender, English fluency, vision, and preference for nature over urban settings were collected. Specifically, participants were asked 1) "Do you prefer nature or urban settings?" and 2) "Do you prefer the nature or urban images presented?" After participants completed all tasks, the program automatically closed and uploaded the data to a secure server.

Materials

Working Memory Capacity- Complex Spans

Each of the tasks described below had the basic structure described. Participants were first asked to memorize items one-at-a-time. Between each presentation of the items, they were asked to complete logical judgments. These sequences of items could be 3-to-10 items long for each block. Each of the two spans had 40 blocks total, with 20 nature images and 20 urban images. For the complex spans, participants received feedback on their logical judgments and were asked to keep their accuracy above 80%. If a participant failed to meet this requirement, the data were excluded from the analysis, however, all participants met these criteria.

Symmetry Span. Participants were asked to memorize the locations of highlighted cells within a matrix in the correct order that the sequence was shown. Between the presentation of the highlighted cells, participants were asked if two different matrices are symmetrical for their logical judgment (Foster, et al., 2015).

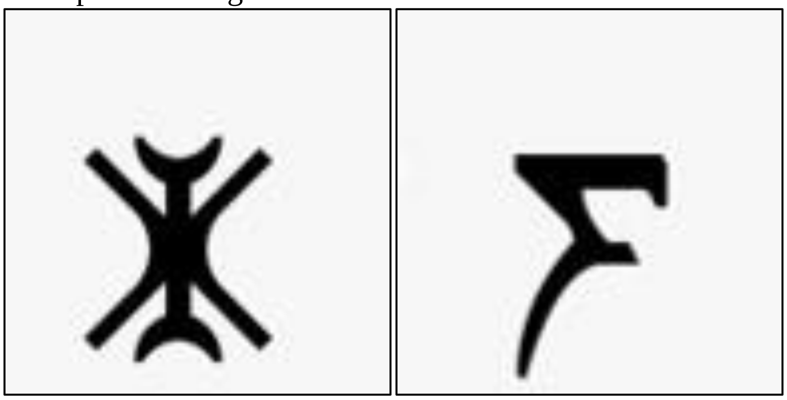
Rotation Span. Participants were asked to memorize the direction and size of arrows in the correct order that the sequence was shown. Between the presentation of the arrows, participants are asked if a letter was facing the correct way after it had been rotated (Foster, et al., 2015).

Primary Memory and Secondary Memory Tasks

These tasks were used in Shipstead et al. (2014) and loaded highest onto primary memory and secondary memory. As with the WMC tasks, some have been modified from letters and numbers to images to prevent cheating (Hicks, et al., 2016). Some of the images were Klingon letters and numbers which are from a language feature in Star Trek. An example of these letters and numbers can be seen in Figure 1.

Figure 1

Examples of Klingon



Note. The symbol of the number 8 (left) and the letter r in Klingon.

Primary memory and secondary memory image and Klingon task. Participants were shown ten lists of 12 images or Klingon letters one-at-a-time after viewing a nature or urban image. Items selected for recognition with seven or fewer recalled or presented items intervening would be a measure of primary memory, whereas any items selected with more than seven items intervening would be a measure of secondary memory, as described in Tulving and Colotla (1970).

Digit (Image) Span (Primary Memory). Participants saw two Klingon numbers one-at-a-time for about four seconds each and were then asked to select the presented items for each trial. If the participants got the two Klingon numbers right for three trials, there were then given three Klingon numbers to remember. This pattern continued until the sequences were 9 numbers long for 30 trials. Before each block of three trials, there was a nature or urban image shown for ten seconds.

Continuous Paired Associates (CPA; Secondary Memory). Participants were asked to study 26 icon pairs one-at-a-time for 30 seconds. Each study trial was intermixed with test trials

2-5 lags behind the corresponding study pair to ensure that the task was measuring secondary memory. Before each test trial, one of the nature or urban images was shown.

Attentional Control Tasks

Antisaccade. Participants saw either a nature or urban image every 8 trials. In each trial, a participant first saw a fixation sign in the middle of the screen for 1-2 seconds. Next a saccade cue “*” was presented on one side of the screen for 300 ms to indicate they should look on the other side of the screen immediately to catch a target letter. On the opposite side of the asterisk, the target letter O or Q was presented for 100 ms and immediately replaced by a pattern mask (##). Participants then indicated which letter was presented (Hutchison, 2007).

Modified Flanker. Participants saw either a nature or urban image every 18 trials. Each trial started with a 900 ms fixation point “+” and then the screen presented five arrows, either all facing the same direction (congruent condition) or the middle arrow facing the opposite direction (incongruent condition). The response deadline for the first block of 18 trials was 1050 ms. If accurate for 15 trials, the response time decreased by 90 ms, otherwise, it is increased by 270 ms for the next block (Draheim et al., 2019). Participants were asked to indicate the direction in which the middle arrow was facing as quickly as possible by pressing the left arrow key or the right arrow key.

RESULTS

Principle Components Analysis

Given that the only factors tested within-subjects were primary and secondary memory, a principal components analysis was run on the primary and secondary memory tasks to ensure that they were measuring separate factors. However, results showed only one factor, as determined by an eigenvalue above 1 (value of 1.91, explaining 47.69% of the variance across the four tasks), even when using varimax rotation. This indicates that both primary and secondary memory tasks were actually measuring one common factor of memory, as shown in Table 1. Given this factor structure, the reset of the analyses treated primary and secondary memory as one construct.[2]

Table 1

Correlations of Memory Tasks and Factor Loadings

Task	Digit Span	CPA	Reog PM	PCA Loading
Digit Span	-			.745
CPA	.350***	-		.748
Recog PM	.125	.034	-	.307
Recog SM	.450***	.488***	.190	.836

Note. Recog PM = Recognition (Primary Memory), Recog SM = Recognition (Secondary Memory), and CPA = Continuous Paired Associates. *** = $p < .001$.

[2] Also, when running a confirmatory factor analysis, the model fit was poor when predicting two factors. A good fitting model has a nonsignificant chi-square statistic, an RMSEA of less than 0.05, a CFI above 0.90, and an SRMR below 0.10. The model fit statistics were poor $\chi 2(3) = 19.333$, $p < 0.001$, CFI = 0.519, RMSEA [90% CI] = 0.279 [0.169, 0.403], SRMR = 0.164].

Task by Image ANOVAs

All descriptive statistics for each task are listed in Table 2 for WMC, Table 3 for attentional control, and Table 4 for memory. Prior to analyses, performance in each task was z-score standardized to allow comparison of Nature effects across tasks and across constructs. These z-scores were computed for nature and urban conditions in each task by first calculating the mean performance separately for nature and urban trials for each participant, then subtracting from these the overall mean performance of the task across participants. I then divided this difference by the overall standard deviation of the task across participants. With the z-transformed scores within each task, I then ran a 2 (Task) x 2 (Image Type, nature vs. urban) ANOVA for each construct. Because I standardized performance within each task, overall mean performance in each task is zero, so there are no main effects of Task. However, the standardization allows me to test for a main effect of Image Type (i.e., does performance differ following nature and urban pictures?) and a Image Type x Task interaction (i.e., is this nature effect greater for one task than others?).

For WMC, the 2 (Symmetry Span vs Rotation Span) x 2 (Nature vs Urban) ANOVA revealed no main effect for Image Type [$F(1,73) = .400$, $p = .530$, $\eta^2_p = .005$] and no Image Type x Task interaction [$F(1,73) = .828$, $p = .366$, $\eta^2_p = .011$]. This is counter to hypothesis 1, as there was no difference in WMC performance between nature and urban trials. The same analysis was conducted on attentional control tasks (Antisaccade vs Modified Flanker), which revealed a main effect of Image Type [$F(1,74) = 5.527$, $p = .021$, $\eta^2_p = .069$] where performance on nature trials ($M_{Nature} = .064$, $SE_{Nature} = .095$) was greater than urban trials ($M_{Urban} = -.064$, $SE_{Urban} = .089$), but no interaction [$F(1,74) = 2.09$, $p = .104$, $\eta^2_p = .035$]. This main effect of

Image Type provides evidence for hypothesis 2 that performance for attentional control tasks improves after viewing nature compared to urban stimuli. Finally, a 4 (Task: Digit Span, CPA, Recognition Primary Memory, Recognition Secondary Memory) x 2 (Image Type: Nature vs Urban) ANOVA was conducted resulting in no main effect for Image Type [$F(1,69) = 1.594$, $p = .211$, $\eta^2_p = .023$]. Due to violation of sphericity for the interaction, Greenhouse-Geisser correction was used. The Task x Image interaction was not significant [$F(1,73) = 1.570$, $p = .205$, $\eta^2_p = .022$]. Primary and secondary memory were collapsed into one general memory construct that does not provide evidence that there is a benefit to memory performance when viewing nature compared to urban stimuli. In summary, the only factor that received a benefit to performance from viewing nature was attentional control.

Table 2

Descriptive Statistics for Raw Scores of Working Memory Capacity Tasks

	Nature					**Urban**				
Task	Mean (SD)	Range	SE	Skew	Kurtosis	Mean (SD)	Range	SE	Skew	Kurtosis
Rot Span	37.43 (15.81)	0-74	1.84	-.19	-.54	36.32 (15.04)	4-70	1.75	-.18	-.26
Sym Span	39.95 (16.05)	0-70	1.86	-.32	-.47	40.08 (16.01)	0-67	1.87	-.43	-.40

Note. Rot Span = Rotation Span and Sym Span = Symmetry Span.

Table 3

Descriptive Statistics for Raw Scores of Attentional Control Tasks

	Nature					**Urban**				
Task	Mean (SD)	Range	SE	Skew	Kurtosis	Mean (SD)	Range	SE	Skew	Kurtosis
Anti-saccade	.77 (.16)	.32-1	.02	-.89	-.10	.76 (17)	.18-.99	.02	-1.04	.87
Modified Flanker	.75 (.10)	.48-.92	.01	-.71	.30	.73 (.08)	.49-.86	.01	-1.10	1.19

Table 4

Descriptive Statistics for Raw Scores of Memory Tasks

	Nature					Urban				
Task	Mean (SD)	Range	SE	Skew	Kurtosis	Mean (SD)	Range	SE	Skew	Kurtosis
Digit Span	3.51 (1.88)	2-8	.22	.96	-.49	3.49 (1.72)	2-8	.21	.92	-.37
CPA	.89 (.20)	.08-1	.02	-2.76	7.44	.87 (.21)	0-1	.02	-2.81	8.48
Recog PM	9.79 (3.44)	0-17	.41	-.30	.17	10.06 (3.38)	0-16	.40	-.35	.25
Recog SM	33.37 (10.27)	5-51	1.23	-.51	-.04	31.23 (10.16)	4-50	1.21	-.35	-.37

Note. Recog PM = Recognition (Primary Memory), Recog SM = Recognition (Secondary Memory), and CPA = Continuous Paired Associates.

Controlling for Nature Preferences

One reason that nature may benefit performance on attention tasks could be preferences for nature compared to urban settings, so each analysis was completed again with the covariates of preference. At the end of the task, participants were asked whether they preferred nature and urban settings and whether they overall liked the nature set of images or the urban set of images. Nature and urban preferences were recoded as 1 and -1 respectively to be run as a covariate. For the individual constructs, adding these covariates did not change the nonsignificant effects for WMC and memory tasks, but caused the effect of Image Type in the attentional control tasks to become marginal [$F(1,61) = 3.304$, $p = .074$, $\eta^2_p = .051$][3]. These results suggest that when accounting for preference, nature's benefit to attentional control performance is attenuated.

[3] Again, processing errors prevented all participants from answering demographics and preference questions. Only those who were able to report preferences were able to be included in these analyses. This resulted in a loss of 28 (12.8%) participants across constructs for these analyses. When conducting the analyses with only those that reported demographics, the main effect of Image Type remained significant. However, the Image Type by Task

Exploratory Analyses for Mechanism of Nature Benefits

Exploratory analyses were conducted to determine which aspects of nature images may account for their benefit on cognition. Fascination and mystery were specifically considered, as these were the two variables that positively predicted performance on the recognition task in Szolosi et al. (2014). To do this, I conducted an item-based analysis for the 40 different nature images and 40 different urban images presented during each task. Each image's performance in the tasks were scored by calculating the average performance across subjects following that image (rather than calculating each subject's average performance across items, as is done in a typical subject analysis). I then transformed this performance to z-scores in the same manner described above. Scores of fascination and mystery were from a previous item-based analysis that was completed on the same images, but in a separate study in which participants on Amazon Mechanical Turk rated images on several characteristics and psychological experiences (Charbonneau, et al., 2021).

The original Image x Task ANOVA for attentional control tasks was replicated by items and then tested again when controlling for both fascination and mystery using ANCOVA. The item-based analysis replicated the original findings with an even stronger main effect of Image Type [$F(1,78) = 6.648$, $p = .012$, $\eta^2_p = .079$], with better performance following nature images than urban images. When controlling for fascination and mystery, the effect became nonsignificant [$F(1,76) = .629$, $p = .430$, $\eta^2_p = .008$], suggesting that these characteristics are indeed important in producing a benefit to attentional control.

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interaction became significant for attentional control tasks such that the effect was greater for the Modified Flanker task compared to the Antisaccade task.

DISCUSSION

The significant effect of nature on attentional control performance supports the ART position that attention is restored when viewing natural stimuli (Kaplan, 1995). Specifically, the effect of nature only reached significance for attentional control.. Through exploratory analyses, potential mechanisms for these benefits may be the higher overall fascination and mystery within the nature images. However, when controlling for preference of natural scenes, this effect within attentional control became marginal, suggesting a portion of this benefit might be due to preference for nature over urban environments.

Stevenson and colleagues' (2018) literature review came to the conclusions that WMC, cognitive flexibility, and attentional control may be particularly sensitive to benefits of nature. However, there was a significant variety in protocol that could not completely be addressed in their meta-analysis, such as the methodology of the intervention and extent to which participants were interacting with natural stimuli. While some experiments were more immersive by having participants go on nature walks, others were virtual manipulations. This study controlled the methodology and the extent to which nature and urban stimuli were viewed. In contrast with Stevenson et al.'s (2018) review, WMC tasks were not found to be significantly affected by nature. This may be due to limited exposure to natural stimuli, compromised construct validity due to the online platform, or that nature only benefits attentional control, but not the other components of WMC, leading to weakened effects when all three components contribute to performance. I will discuss each of these possibilities in turn.

First, the limited time viewing the nature and urban images could be why there was not significant difference for the WMC or memory tasks. However, viewing these images have shown performance differences in other studies. The nature images taken from Szolosi et al. (2014) created a benefit for recognition after only 5 seconds of viewing the image. The urban images from Berman et al. (2008) showed significantly worse performance compared to nature images on attentional tasks when viewing the images for 7 seconds each. Therefore, these stimuli produce differences even when viewed for short durations. Also, the significant difference in attentional control performance between nature and urban trials indicates that the intervention was successful but may have been a weak manipulation due to being online.

Second, a related argument could be that the error introduced by the online platform could have decreased the sensitivity of measuring each desired construct, therefore, compromising construct validity. This error would most likely come from cheating or disengagement from the tasks. However, the WMC tasks have been shown to be a valid measure of individual differences in WMC in the online platform if letters and numbers are avoided to prevent cheating (Hicks et al., 2016). This same criterion was used for all tasks, which should limit problems associated with cheating. Also, none of the participants failed the attention checks that were placed randomly in each set of tasks, indicating engagement throughout the study. Therefore, two likely sources of error were not present in the online intervention.

Third, consistent with ART, that data showed a benefit to attentional control specifically during nature compared to urban trials, but no benefit to WMC, counter to Stevenson et al.'s (2018) findings. If nature benefited WMC and not attentional control, it would have been expected for the other components of WMC, primary memory and secondary memory , to receive performance benefits from viewing nature. However, no such benefits were found. Instead, attentional control specifically may have been driving the WMC benefit obtained by

Stevenson et al. (2018). They also concluded that attentional control was benefited by nature, but to a less reliable degree, but this may be due to attentional control tasks correlating poorly (Draheim et al, 2019). This study, however, took into consideration Draheim et al.'s (2019) suggestions to use accuracy-based measures of attentional control and showed a significant benefit to attentional control performance after viewing nature images compared to after viewing urban images. This provides additional evidence that attentional control is the likely specific process that is benefited by nature.

Future Research

ART explains some of the mechanisms that may elicit benefits to cognition, but other mechanisms such as preference should be examined in future research. The four mechanisms proposed to affect the benefits of nature on attention restoration are extent, compatibility, being away, and fascination. The small extent to which the images were presented were controlled throughout the study so this mechanism could not be assessed in this study, but has shown effects elsewhere (Szolosi, et al., 2014). Compatibility and being away were also not investigated in this study. Previous literature has shown that people who work, go to school, and live in urban areas might perceive nature as restorative and an "escape" from their typical environment. Scopelliti & Vittoria (2004) surveyed adults throughout their lifespan about their favorite places to go for restoration. The sense of being away from their typical routine was greater for younger adults, compared to older adults, and the component of being away was qualitatively indicated more often by younger adults when asked about reasons for picking their restorative environments. Therefore, the preference for nature was a mechanism tested to determine whether the benefit of nature is due to societal preferences for nature. Results showed that controlling for preference did reduce the beneficial effect of nature on attentional control tasks to marginal. Finally, fascination and mystery were examined as a mechanism for nature's benefit on cognition, given Szolosi et al.'s (2014) findings of benefits to recognition. When controlling for these specific mechanisms, the effect of nature again became nonsignificant. Thus, it is likely that preference, fascination, and mystery are all related to nature's benefit to cognition.

Future research should examine the mechanisms outside of those defined by ART such as characteristics that may elicit physiological responses (e.g. brightness of setting, complexity of settings, and coherence of settings). Also, given the smaller effect size when conducting the subject-based analysis compared to item-based analyses, this may indicate that some subjects are more likely to receive cognitive benefits from natural stimuli compared to others (Bengson & Hutchsion, 2007). These differential benefits across subjects may be from limited exposure to nature (Tallis et al., 2018) or individual differences in cognitive ability. Finally, given the small effect size, future online nature interventions should increase the extent to which participants interact with nature to determine if this could increase the size of the effect and make it more meaningfully useful.

CONCLUSION

The purpose of this study is to clarify which cognitive abilities are benefited by nature exposure and whether this can be done online for those who may not have access to nature. The results suggest attentional control performance is improved after viewing natural stimuli. Therefore, with enough viewing time, online nature interventions could help many receive attentional benefits that may not be accessible in urban areas. For instance, this type of intervention could help surgeons doing a complicated and long procedure by using a momentary rest break to look at a natural image in the room to help attention. It may also help students taking a test in the classroom by helping maintain attentional focus, rather than mind wandering about test anxiety or other concerns. Using nature images in urban settings could potentially give those who use attention to the point of fatigue a chance to receive attentional benefits.

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