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40-second green roof views sustain attention: The role of micro-breaks in attention restoration

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A R T I C L E I N F O

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A B S T R A C T

Based on attention restoration theory we proposed that micro-breaks spent viewing a city scene with a flowering meadow green roof would boost sustained attention. Sustained attention is crucial in daily life and underlies successful cognitive functioning. We compared the effects of *40-s* views of two different city scenes on 150 university students' sustained attention. Participants completed the task at baseline, were randomly assigned to view a flowering meadow green roof or a bare concrete roof, and completed the task again at post-treatment. Participants who briefly viewed the green roof made significantly lower omission errors, and showed more consistent responding to the task compared to participants who viewed the concrete roof. We argue that this reflects boosts to sub-cortical arousal and cortical attention control. Our results extend attention restoration theory by providing direct experimental evidence for the benefits of micro-breaks and for city green roofs.

1. Introduction

Views of nature can boost attention and mood over minutes to hours (see Bratman, Hamilton, & Daily, 2012 for a recent review). But, researchers speculate, this might occur after just brief glances of nature (Kaplan, 1993, 2001). Attention, in particular, can improve after experiencing (Hartig, Evans, Jamner, Davis, & Gärling, 2003; Lee, Park, Tsunetsugu, Kagawa, & Miyazaki, 2009) or viewing 'restorative' nature scenes (Berman, Jonides, & Kaplan, 2008, Study 1; Berto, 2005). According to Attention Restoration Theory (ART; Kaplan, 1995; Kaplan & Kaplan, 1989), people typically perceive these scenes as effortlessly *fascinating*, *extensive* enough to promote a sense of *being away* from everyday concerns, and as being *compatible* with their needs (Kaplan & Kaplan, 1989). Nature, researchers believe, is higher in these restorative components (Kaplan & Kaplan, 1989), and more able to boost waning attention (Berman et al., 2008) than cities.

Evidence is mounting to show that nature in cities is also restorative (Berman et al., 2008, Study 2; see Hartig, Mitchell, de Vries, & Frumkin, 2014 for a recent review). The majority of this research has, however, focused largely on parks (Hartig et al., 2014), which may not be visible from many points around the city. People living and working in high-rise city buildings, who have restricted views of nature, may instead have views of new forms of city vegetation like "green roofs". Green roofs are typically installed on building rooftops for environmental benefits (Oberndorfer et al., 2007), but may also provide opportunities for boosting attention for thousands of employees working in nearby offices (Loder, 2010).

We expand on previous research by directly investigating the attention benefits of viewing a green roof during a micro-break between tasks. We use neuroscience tests and techniques to examine the underlying process of attention restoration. This paper draws together research on the attention boosting benefits of viewing nature with the neural underpinnings of attention. We hypothesize that viewing a green roof during short micro-breaks boosts attention (Kaplan, 1993, 2001); our research provides an empirical test.

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1.1. Urban greening provides attention restoration opportunities

Living and working in busy, overcrowded and information rich cities drains the mental resources controlling attention (Herzog, Black, Fountaine, & Knotts, 1997; Kaplan, 1995). This happens when people direct attention towards tasks while drawing on an inhibitory mechanism to block out external distractions (Kaplan, 1995). Attention restoration theory (Kaplan, 1995; Kaplan & Kaplan, 1989) argues that restorative nature gently captures attention involuntarily in an automatic reflexive manner via fascination, reducing demands on the limited resources available to voluntarily direct attention (Berman et al., 2008; Kaplan, 1995).

Views of restorative vegetation in high density cities have traditionally been limited to nearby ground-level nature, including street trees and small parks (Kaplan, 1993; van den Berg, Jorgensen, & Wilson, 2014). New forms of city vegetation like green roofs, which consist of low-growing plants in thin soil-like mixes over drainage layers (Oberndorfer et al., 2007) may, however, provide similar opportunities for attention restoration. Green roofs present exciting possibilities for designing future cities as they are capable of mitigating storm-water, providing biodiversity habitat (Oberndorfer et al., 2007), and acting as a climate change adaptation strategy (Georgescu, Morefield, Bierwagen, & Weaver, 2014). They are becoming widespread as policies in many cities mandate their construction (Carter & Fowler, 2008) for their many environmental benefits. Viewing even limited amounts of vegetation (Kaplan, 1993; Ulrich, 1986) can provide the attention-restoring benefits of nature (Herzog, 1989), which highlights a possible role for city green roofs in restoring attention. Thus, our study investigates the extent to which viewing a green, rather than concrete roof scene, during a brief micro-break may boost attention.

1.2. A cognitive account of sustaining attention

The capacity to maintain control of attention over time, known as sustained attention, is vital for many tasks performed everyday (Maclean et al., 2010; Sarter, Givens, & Bruno, 2001). Sustained attention is a fundamental component of attention involved in learning and memory (Cowan, 1995), which underlies general cognitive ability (Maclean et al., 2010; Sarter et al., 2001). Maintaining attention is critical (Schwartz & Kaplan, 2006; Warm, Parasuraman, & Matthews, 2008) for focusing on tasks (Lee, Gino, & Staats, 2014), blocking out distractions (Posner, 2011; Schwartz & Kaplan, 2006), and behaving positively towards others (Muraven & Baumeister, 2000; Podsakoff, Whiting, Podsakoff, & Blume, 2009). Controlling attention, however, requires effort and cannot be maintained over extended periods of time (Maclean et al., 2010; Sarter et al., 2001). Attempting to maintain attention over the day may even diminish wellbeing and productivity (Jett & George, 2003; Sonnentag, Binnewies, & Mojza, 2010).

Neuroimaging studies show that sustaining attention involves two different networks in the brain (Maclean et al., 2009; Sarter et al., 2001). Efforts to maintain control of attention towards work tasks are processed cortically through the dorsal attention network (Paus et al., 1997; Sturm & Willmes, 2001), while external distractions are processed sub-cortically through the ventral attention network (Corbetta & Shulman, 2002; Maclean et al., 2009). Sustaining attention is difficult, however, with control over attention declining in as little as 5 min (Warm et al., 2008).

According to the attention-resource model (Davies & Parasuraman, 1982; see Warm et al., 2008 for a recent review), sustaining attention control exhausts underlying mental resources (Maclean et al., 2010). This model is supported by neural, behavioral and self-report evidence. Waning attention is associated with subjective perceptions of increased task workload (Warm, Dember, & Hancock, 1996) and restricted blood flow (Hitchcock, Dember, Warm, Moroney, & See, 1999) to areas associated with attention control (Weissman, Roberts, Visscher, & Woldorff, 2006) immediately before lapses in attention. These brain areas are less active after performing demanding tasks, highlighting the persistent effects of depleted mental resources (Lim et al., 2010). In experimental conditions, alerting tones and warning cues can boost sustained attention (McLean et al., 2009; O'Connor, Robertson, & Levine, 2011), but it is unlikely that these are practical solutions for daily life.

Drawing on the attention-resource model of sustained attention (Davies & Parasuraman, 1982; Warm et al., 2008) and attention restoration theory (Kaplan & Kaplan, 1989), we propose that viewing nearby nature in the form of green roofs, could provide a restorative experience to boost the mental resources controlling attention. Thus, participants viewing the concrete, but not the green roof, should show typical declining attention over the course of a sustained attention task. In line with existing speculation (Kaplan, 1993; 2001), we suggest that viewing restorative nature may boost attention after a brief micro-break. We define micro-breaks as short, informal breaks which can occur spontaneously throughout the day (Henning, Sauter, Salvendy, & Krieg, 1989), possibly in response to waning attention (Jett & George, 2003) and are less than several minutes in length.

The propensity for everyday lapses of sustained attention can be measured using the Sustained Attention to Response Task (Robertson, Manly, Andrade, Baddeley, & Yiend, 1997). Performance on this task activates the brain networks involved in sustaining attention and ignoring external distractions (Manly et al., 2003). Consistent variability in responding on this task reflects participants being able to sustain their attention (Barkley, 1997; Bellgrove, Hester, & Garavan, 2004), avoiding fluctuations in overall arousal and momentary slips in attention control.

To pinpoint the underlying networks affected by viewing nature, and empirically evaluate the claims of ART, we draw on a novel neuroscience analysis technique called the fast Fourier transform. This technique partitions participant response variability into two forms: fast-frequency moment-to-moment variability and slow-frequency gradual variability (Johnson, Kelly, et al., 2008). As the name suggests, moment-to-moment variability reflects quick momentary fluctuations in participant responding over the course of the task. This is argued to indicate changes in cortical attention control (Johnson et al., 2007; Johnson, Kelly, et al., 2008), or, using the terminology of ART, momentary lapses of voluntary directed attention (Kaplan, 1995). Gradual variability on the other hand, reflects gradual speeding up or slowing down in participant responding over the course of the task. This is argued to indicate changes in sub-cortical arousal (Johnson et al., 2007; Johnson, Kelly, et al., 2008), or, using the terminology of ART, gradual changes in involuntary attention (Kaplan, 1995). Innovatively drawing on this technique and partitioning each participant's response variability into moment-to-moment and gradual variability will allow us to empirically assess the dual process of attention restoration. Drawing on attention restoration theory (Kaplan & Kaplan, 1989), we expect that the green roof will gently stimulate sub-cortical arousal processes and boost cortical attention control. This will be reflected in less moment-to-moment and gradual variability and fewer errors made on the task, compared to participants viewing the concrete roof.

Hypothesis 1: People will perceive a green roof as more restorative than a concrete roof.

Hypothesis 2a: After viewing the green roof participants will show less moment-to-moment variability in responding on the task, as compared to participants who viewed the concrete roof.

Hypothesis 2b: After viewing the green roof participants will show less gradual variability in responding on the task, as compared to participants who viewed the concrete roof.

Hypothesis 2c: After viewing the green roof participants will make fewer errors on the task, as compared to participants who viewed the concrete roof.

2. Methods

2.1. Participants

The 150 participants (*M* age = 20; 71% female) were recruited from a university psychology research experience program and the broader student population. Psychology students received research credit. Treatment conditions were allocated using random numbering stratified within each block of 10 participants.

2.2. Measures

2.2.1. Restorativeness of the view

To assess the extent to which participants perceived that the green roof could restore their attention, we used the Perceived Restorativeness Scale (Hartig, Korpela, Evans, & Gärling, 1997). Participant responses were assessed on a 6-point Likert scale (1 = *not at all*; 6 = *very much so*). Consistent with previous green roof studies (Lee, Williams, Sargent, Farrell & Williams, 2014; White & Gatersleben, 2011), 12 items were selected, with items like "There are landmarks to help me get around" removed as they were not relevant to the scenes. The item "I would like to spend more time looking at this view" was removed as it did not load with the other items of the scale. The final scale included 11 items and had acceptable reliability (Cronbach's $\alpha = 0.76$).

2.2.2. Attention

To assess the influence of briefly viewing a green roof on attention control, we used the random version of the Sustained Attention to Response Task (Johnson, Kelly, et al., 2008; Robertson et al., 1997). The SART was presented in a computer laboratory using E-Prime. A sequence of digits was presented to participants and they were asked to respond to every digit except digit '3', by pressing the left arrow key on the computer keyboard when the response cue appeared. The timing of the task involved a single digit appearing on the screen for 313 ms, followed by a mask for 125 ms, after which a response cue (a bold cross) appeared for 63 ms, and then a second mask for 375 ms and a fixation cross for 563 ms. Participants were presented with 225 digits, 108 for each half (the first 9 digits were excluded in the half analyses), in a pseudo-random sequence taking 5.5 min. The total inter-stimulus interval was 1439 ms. The digit sequence was identical for all participants, with 13 and 11 presentations of the digit '3' (go-trial) in the first and second halves of the SART respectively. The response cue was used to reduce any speed/accuracy tradeoffs in participant responding. Digits, response cue and fixation cross were white against a black background.

2.3. Procedure

Before beginning the SART participants were informed of the aims and scope of the study, and completed a 10-trial practice task. After completing the baseline SART participants received a micro-break. They were informed that there were no questions related to the break and to look freely at the view (Berto, 2005). Instructions appeared for 10 s, followed by the city scene for 40 s. Break length, obtained though a pilot study (*N* = 34), involved participants self-determining the length of their viewing time (see Henning et al., 1989 for a similar methodology). During the break, half the participants were randomly allocated to view a city scene with a concrete roof, while the other half viewed the same city scene with a "green roof" planted with a meadow containing taller green grass and yellow flowers (Lee, Williams, et al., 2014) (see Fig. 1). Following this, participants completed a second SART and rated the restorative components of the view using the Perceived Restorativeness Scale (Hartig et al., 1997).

2.4. Data analyses

Each participant's response times and standard deviation of response time (SDRT) were calculated for all go-trials (all digits except '3'). The data were analyzed for errors of omission and commission. An error of omission occurred when the participant failed to respond to any of the digits except '3', and an error of commission resulted when the participants incorrectly responded to the '3' digit.

Moment-to-moment variability encapsulated all variability within one SART cycle (nine digits in a row), while gradual variability encapsulated all variability longer than one SART cycle. Using the methodology of Johnson et al. (2007), we used the fast Fourier transform to partition response time variability into fast-frequency moment-to-moment variability and slow-frequency gradual variability. To calculate moment-to-moment variability, each participant's response times on the SART were converted to

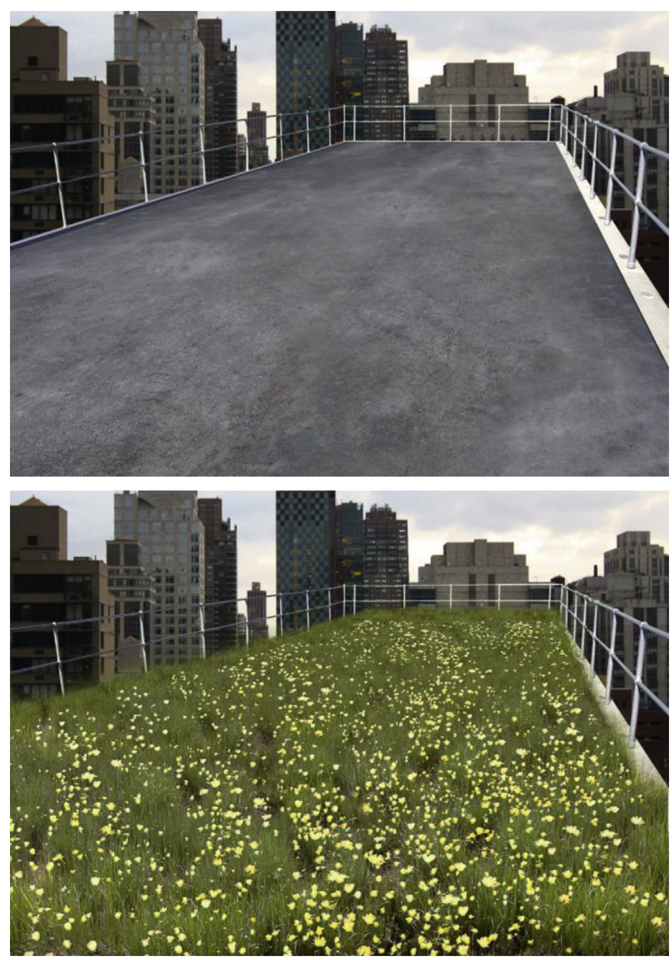

Fig. 1. The simulated views shown to participants during the 40 s break. The top image is the city scene with a bare concrete roof, while the bottom image is the city scene with a green roof planted with a flowering meadow.

time-series data, detrended and separated into seven segments. Each segment consisted of 75 data points with an overlap of 50 points and was Hamming-windowed and zero-padded for a total length of 450 points. The magnitude of the discrete Fourier transform was squared to calculate the periodogram for each segment which was then averaged across the entire SART block of seven segments. This created one power spectrum for each participant across each SART block; the first half SART comprised the average of the first three segments, while the second half SART comprised the average of the final four segments. To calculate gradual variability, the time-series data was not separated into different segments or detrended. This ensured that the linear components of the response time variability could be analyzed as these linear shifts may reflect meaningful gradual changes over the course of the SART (Johnson et al., 2007).

To assess changes in sustained attention over the task, data for all measures, except the gradual variability, were calculated for each half of each SART block. Three participants made ≥30 omission errors, indicating they were not performing the task correctly, and were removed from all analyses. Thus, 147 participants were included in the error analyses. Mean response time and SDRT data were normally distributed and were analyzed using ANOVAs [Group (green roof, concrete roof) x SART Block (baseline, post-treatment) x Half (1st, 2nd)] and Bonferroni-adjusted pairwise comparisons. SDRT had four outliers (≥2.96 *SD*) removed from response consistency analyses. Thus, 143 participants were included in the SDRT, moment-to-moment variability, and gradual variability analyses. Moment-to-moment and gradual variability analyses, omission and commission error data were non-normal in distribution. Based on our study hypotheses, planned Mann–Whitney U tests were used to assess between-group differences. Where Friedman's ANOVA showed significant within-group differences, a targeted Wilcoxon Signed Ranks test was used to identify response changes associated with significant between-groups results.

Scores on the Perceived Restorativeness Scale were normally distributed, with no outliers ≥2.96 standard deviations from the mean. Only those participants included in all SART analyses were used. Two additional participants were removed as they failed to respond to ≥8 of the 11 questions, so that a total of 141 participants were included in the final analyses. An independent groups *t*-test was used to compare the perceived restorativeness of the flowering meadow green roof and the concrete roof scenes. Levene's test for equality of variances was not significant ($p = .102$).

3. Results

3.1. Perceived restorativeness

To test hypothesis 1, we examined participants' perceptions of the restorativeness of the two different city scenes. We expected, and observed, that participants felt that the flowering meadow green roof scene ($M = 3.46$, $S.E. = .10$) was more restorative that the concrete roof scene ($M = 2.93$, $S.E. = .12$), ($t(140) = -3.48$, $p = .001$).

3.2. Overall response variability

Viewing the flowering meadow green roof scene for 40 s was associated with a more consistent pattern of responding, suggesting higher sustained attention, measured by the standard deviation in response time [$F(1, 141) = 12.71$, $p < .001$] (see Table 1). There was no baseline difference between participants viewing the green and concrete roofs [$F(1, 141) = 0.00$, $p = .975$, r = .00], but there was a significant difference in performance after viewing the scenes [$F(1, 141) = 5.20$, $p = .024$, r = .19]. Participants viewing the green roof showed less response variability post-treatment [$F(1, 141) = 5.00$, $p = .027$, r = .19], whereas those viewing the concrete roof showed a significant increase [$F(1, 141) = 7.86$, $p = .006$, r = .23]. There was also a main effect of SART half such that both groups performed the SART with higher response variability in the 2nd half of each task session compared to the 1st half [$F(1, 141) = 4.43$, $p = .037$]. This is a typical time-on-task response pattern. The fast Fourier transform was then used to separate the overall response variability into fast-frequency moment-to-moment variability and slow-frequency

Table 1
Descriptive Statistics Showing the Mean ± SE for Response Time and Standard Deviation of Response Time in Seconds, and the Median and Interquartile Range (IQR) for Moment-to-Moment Variability and Gradual Variability on the Sustained Attention to Response Task (SART) in Power, for Participants Viewing the Green or Concrete Roof. Median and Interquartile Range (IQR) as well as the Mean ± SE are Presented for Omission and Commission Errors to Provide Additional Information about the Differences Between Groups.[b]

	Baseline SART								Post-treatment SART							
	1st half[a]				2nd half[a]				1st half[a]				2nd half[a]			
	Median	IQR	Mean	S.E.	Median	IQR	Mean	S.E.	Median	IQR	Mean	S.E.	Median	IQR	Mean	S.E.
SD of response time																
Concrete roof			95.37	3.96			107.38	4.75			102.27	4.88			116.46	5.67
Green roof			97.30	4.20			101.24	5.05			90.67	3.59			96.41	4.05
Moment-to-moment variability																
Concrete roof	130,595	123,903			147,329	161,752			137,007	143,317			181,592	189,455		
Green roof	126,975	122,784			123,983	129,800			115,309	128,040			136,414	118,099		
Gradual variability																
Concrete roof	153.13	264.40							195.48	244.87						
Green roof	138.24	169.25							116.69	153.89						
Omission errors																
Concrete roof	0	0	.65	.30	0	1	.50	.13	0	0	.63	.19	0	2	1.43	.17
Green roof	0	0	.49	.15	0	1	.63	.20	0	0	.37	.11	0	1	.68	.16
Commission errors																
Concrete roof	1.5	5	2.54	.31	2	3	2.86	.30	2	4	3.42	.37	3	4	3.32	.31
green roof	1	3	1.97	.25	2	3	2.52	.28	2	3	2.76	.31	2	3	2.83	.31
Mean response time																
Concrete roof			541.64	16.13			525.92	18.54			525.01	19.90			501.56	18.25
Green roof			551.64	17.31			526.35	18.13			526.73	18.40			519.29	19.49

[a] There were 13 and 11 presentations of the digit '3' (go-trial) in the first and second SART halves respectively. This was identical for both groups and both SART blocks.
[b] The median and interquartile range are most commonly reported for non-parametric analyses. The mean and standard deviation are also reported to provide more information about omission and commission errors, but caution should be used when interpreting these statistics in relation to non-normal data.

gradual variability in participant responding on the task.

3.2.1. Fast-frequency moment-to moment response variability

To test hypothesis 2a, we examined fast-frequency moment-to-moment variability in responding on the task. We expected, and observed, that viewing the flowering meadow green roof scene was associated with less moment-to-moment variability compared to the concrete roof scene, reflecting better attention control for these participants (Johnson, Kelly, et al., 2008). Immediately after the break, in the 1st half of the task, there was no significant difference between participants viewing the green or concrete roof [U = 2450, p = .336, r = –.04]. By the 2nd half of the task, however, the concrete roof group showed greater moment-to-moment variability indicating significantly worse attention control, compared with the green roof group [U = 1994, p = .012, r = –.19] (see Fig. 2). Only participants in the concrete roof group showed worsening moment-to-moment variability over time [concrete roof, $\chi^2(3) = 29.05$, $p < .001$; green roof, $\chi^2(3) = 2.14$, $p = .536$], with higher moment-to-moment variability in the 2nd half of the task after viewing the scene, compared with the 2nd half of the task at baseline [$z = -1.77$, p = .039, r = –.15]. At baseline, there was no difference between participants viewing the green or concrete roof [1st half, U = 2445, p = .380, r = –.03, 2nd half, U = 2318, p = .169, r = –.08].

3.2.2. Slow-frequency gradual response variability

To test hypothesis 2b, we examined slow-frequency gradual variability in responding over the course of the task. We expected, and observed, that viewing the flowering meadow green roof scene was also associated with less gradual variability compared to the concrete roof scene, reflecting higher sub-cortical arousal for these participants (Johnson, Kelly, et al., 2008). At baseline, there was no difference between participants viewing the green or concrete roof [U = 2231, p = .148, r = –.12]. After viewing the scene, the green roof group performed the task with significantly less gradual variability compared with the concrete roof group [U = 1967, p = .009, r = –.20] (see Fig. 3). There was no change in gradual variability, however, for either group before and after viewing the scene [green roof, $z = -1.35$, p = .090, r = –.09, concrete roof, $z = -0.76$, p = .225, r = –.05].

3.3. Response errors

To test hypothesis 2c, we next analyzed the data for errors of omission and commission; the extent to which participants failed to respond to non-target digits or incorrectly responded to the target digit respectively. We expected, and observed, that after viewing the flowering meadow green roof scene, participants made less omission errors compared to participants viewing the concrete roof, reflecting higher sub-cortical arousal for these participants (Johnson, Kelly, et al., 2008). Immediately after the break, in the 1st half of the task, there was no significant difference between participants viewing the green or concrete roof [U = 2659, p = .403, r = –.02]. By the 2nd half of the task, however, the concrete group

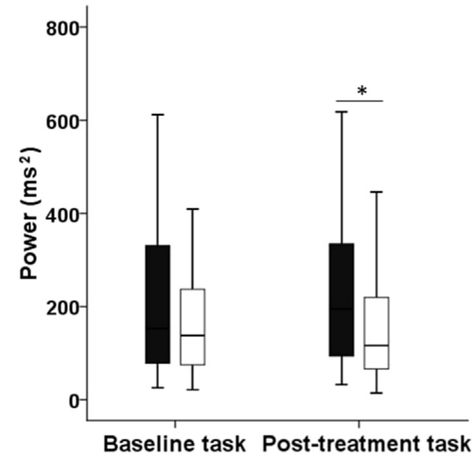

Fig. 3. Boxplot of the median and variance of gradual changes in response variability (reported as power). Participants viewed a concrete (gray boxes) or green roof (white boxes). Data shown for baseline and post-treatment tasks. Asterisk denotes a significant difference between participants viewing a concrete and a green roof at post-treatment (p = .009). There was no difference at baseline (p = .148).

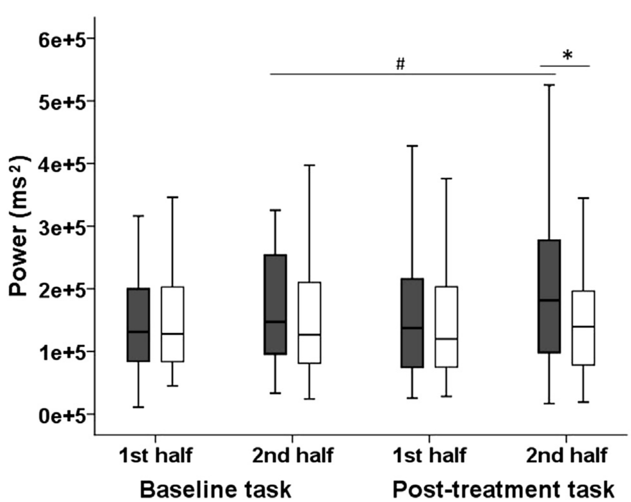

Fig. 2. Boxplot of the median and variance of moment-to-moment response variability (reported as power). Participants viewed a concrete (gray boxes) or green roof (white boxes). Data shown for the 1st and 2nd half baseline task, and the 1st and 2nd half post-treatment task. Asterisk denotes a significant difference between participants viewing a concrete and green roof (p = .012). Hash denotes a significant increase in variability for participants viewing the concrete roof in the 2nd half task from baseline to post-treatment (p = .039).

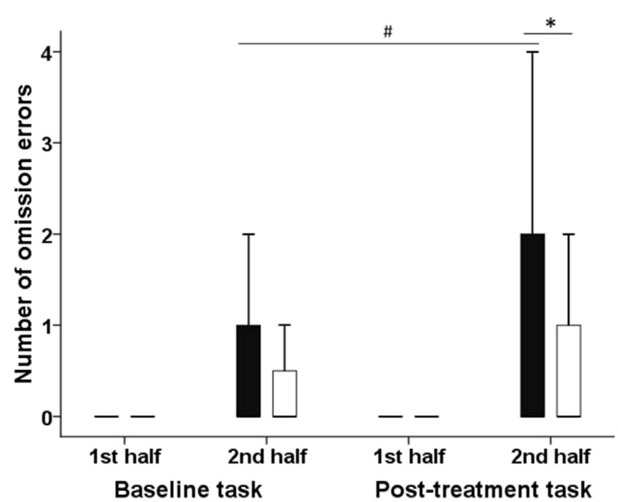

Fig. 4. Boxplot of the median and variability of the number of omission errors. Participants viewed a concrete (gray boxes) or green roof (white boxes). Data shown for the 1st and 2nd half baseline task and the 1st and 2nd half post-treatment task. Asterisk denotes a significant difference between participants viewing a concrete and green roof (p = .041). Hash denotes a significant difference, for participants viewing the concrete roof, who made significantly more errors in the 2nd half task from baseline to post-treatment (p < .001).

made significantly more omission errors than the green roof group [U = 2318, $p = .041$, r = –.14], (see Fig. 4). Only participants viewing the concrete roof showed worsening numbers of omission errors over time [concrete roof, χ^2 (3) = 20.06, $p < .001$, green roof, χ^2 (3) = 2.60, $p = .454$], with higher omission errors in the 2nd half of the task after viewing the scene, compared to the 2nd half of the task at baseline [$z = -3.06$, $p = .001$, r = –.25]. At baseline the two groups made a similar number of omission errors [1st half, U = 2647, $p = .385$, r = –.02, 2nd half, U = 2691, $p = .484$, r = .00].

We did not observe differences in commission errors between the groups at baseline [1st half, U = 2452, $p = .164$, r = –.08, 2nd half, U = 2479, $p = .194$, r = –.07], or after viewing the scene [1st half, U = 2369, $p = .098$, r = –.11, 2nd half, U = 2361, $p = .093$, r = –.11]. This suggests that there was no difference in impulsive responding (Johnson et al., 2007) between participants viewing the green and concrete roofs. Thus, hypothesis 2c was supported for omission, but not commission errors on the task. Consistent levels of commission errors likely reflect healthy response inhibition levels for a university student population (Johnson et al., 2007).

3.4. Response speed

We analyzed the speed of participant responses to ensure that there were no significant differences between treatment groups which could account for changes in response variability and errors on the task. There was no difference in mean response times for participants viewing the green or concrete roofs [$F(1, 145) = 0.10$, $p = .754$]. This reflects participants responding to the response cue, which was designed to reduce speed/accuracy tradeoffs. All participants had faster response times in the post-treatment SART compared with baseline [$F(1, 145) = 5.40$, $p = .022$, r = .19], and in the 2nd half compared with the 1st half of both tasks [F (1, 145) = 14.89, $p < .001$, r = .31]. These are typical results, showing participants becoming accustomed to the task.

4. Discussion

Our study used neuroscience and self-report methods to test the extent to which brief glimpses of a flowering meadow green roof scene, compared to a concrete roof scene, were associated with better sustained attention. Our results are consistent with the attention-resource model (cf. Warm et al., 2008) and attention restoration theory (Kaplan & Kaplan, 1989). The green roof scene was perceived by participants as more restorative, as well as boosting their attention compared to participants viewing the concrete scene, who showed worsening attention over the course of the task. After 40 s viewing the green roof scene, participants performed the random SART with significantly lower gradual and moment-to-moment variability in responding, and made significantly less omission errors, compared with participants who viewed the concrete roof. Overall our hypotheses were supported; only commission errors on the task did not differ significantly between groups, which reflects our university student sample who are likely to have good impulse control (Johnson et al., 2007).

This study makes three important contributions to the literature. First, in line with speculation on the benefits of micro-breaks (Kaplan, 1993; 2001), we have provided the first evidence that attention boosts can occur after as little as 40-s viewing a green roof scene. Previous research shows benefits after minutes-to-hours viewing nature (see Bratman et al., 2012 for a review). Our results highlight boundary conditions of attention restoration theory and suggest that nature can provide cognitive benefits in much shorter timeframes, and in smaller amounts than previously demonstrated. It is interesting to note that while our results lend strong support for ART, the rapidity of changes in attention that we observed (suggesting changes in underlying neural networks) may also be consistent with psychophysiological accounts (i.e. Ulrich, 1984).

Second, the significance of our results is amplified because we demonstrated these boosts, offsetting waning attention, after viewing a green roof scene with limited amounts of low-growing grassy vegetation surrounded by high rise buildings. Ours is the first study to examine the attention restoring benefits of green roof vegetation and adds support to recent research showing attention restoration benefits across different types of urban vegetation (van den Berg et al., 2014). Our findings reveal the extent to which this novel form of city nature, primarily constructed for environmental benefits, can also provide benefits for people living and working in cities.

Third, we draw on a novel neuroscience technique to suggest alternative methods for analyzing response variability data. The fast Fourier transform has been used to analyze different neuroscience tasks (Castellanos et al., 2005; Johnson et al., 2007) and provides a unique contribution to analyze the attention restoring benefits of nature. In our study, using this technique allowed us distinguish different forms of response time variability and provide initial evidence of the dual neural process of attention restoration. The cortical attention control benefits of viewing nature are widely documented via boosts to memory (Tennessen & Cimprich, 1995), response inhibition (Hartig et al., 2003; Taylor, Kuo, & Sullivan, 2002), and executive attention (Berman et al., 2008). We argue that our results might provide behavioral evidence suggesting changes to sub-cortical arousal *and* cortical attention control after a micro-break spent viewing a green roof.

Our results have particular implications for the workplace where sustained attention is vital for performance. They provide a preliminary indication that micro-break views of a green roof could help employees top-up their attention resources as they become depleted in the workplace (Mccoy & Evans, 2005). Views of nature are processed effortlessly (Berto, 2005; Kaplan & Kaplan, 1989), and can promote relaxation (Korpela & Kinnunen, 2010). Relaxing between demanding tasks can provide time for reflection and may reduce tension (Hobfoll & Shirom, 1993), but employees facing high demands at work may skip scheduled work breaks (Rogers, Hwang, & Scott, 2004). Thus, frequent micro-breaks throughout the day may offset the demands on attention associated with maintaining work performance and could help boost productivity (Balci & Aghazadeh, 2003), particularly when they are spent viewing nature. Setting aside the many environmental benefits that actual vegetation can provide, our results also highlight possibilities for using computer wallpapers and screensavers to maximize opportunities for viewing nature, albeit virtually, during brief micro-breaks between tasks.

There are limitations to our study, which suggest important directions for future research. First, our study used a green roof scene to test the attention restoring benefits of nature. Although the use of nature scenes is common in attention restoration research (e.g., Berman et al., 2008, Study 1; Berto, 2005), there is some debate about the extent to which they are effective surrogates for nature (Daniel & Meitner, 2001; de Kort, Meijnders, Sponselee, & Ijsselsteijn, 2006). It would be worthwhile, therefore, to conduct follow-up research which assesses the influence of views of a real green roof on attention. On a related note, our flowering meadow green roof differed from the concrete roof on several different vegetation characteristics; color, plant life-form, and flowering. Thus, in the future, research could attempt to disentangle the relative importance of these different characteristics for restoring attention. This would assist with selecting vegetation, as well as designing natural areas in and around workplaces.

Second, we have used a behavioral neuroscience task to point to the dual networks through which viewing nature may boost attention. Prior imaging research confirms that the SART activates the brain networks involved in sustaining attention (Manly et al., 2003), but it would be prudent to conduct follow-up research which uses simultaneous neuro-imaging techniques in conjunction with the SART to further validate our findings. Based on our research, and in conjunction with attention restoration theory (Kaplan, 1995; Kaplan & Kaplan, 1989), we would predict that viewing the green roof should affect both the ventral attention network involved in arousal processes (Critchley, Melmed, Featherstone, Mathias, & Dolan, 2002; Nigg, 2005) as well as the dorsal attention network involved in controlling attention (Robertson & Garavan, 2004).

Third, our use of a neuroscience test provides an indication of people's underlying cognitive functioning. In order to assess the extent to which our results translate to real world contexts like the workplace, follow-up research should focus on the influence of green roof views on real work tasks. In addition, our sample of student participants was highly specific, which could limit the generalizability of our results. Students are required, however, to maintain their attention over long periods of time as well as perform repetitive and effortful tasks which are common across many different settings including healthcare (Weinger & Englund, 1990), and transportation (Naweed, 2013). Our results also contribute to the literature on the benefits of nature in education settings for both students, and potentially, teachers (Gulwadi, 2006; Han, 2009). Follow-up research could examine the benefits of nature micro-breaks across different occupational settings as well as exploring alternative performance outcomes including creativity, team-work, and organizational citizenship behaviors. It should be noted that our analyses revealed small-to-moderate effect sizes and this should be taken into account when interpreting our results. In light, however, of our university student sample who are highly practiced in sustaining attention, our modest city green roof intervention, and brief 40-s exposure, these effect sizes suggest that the benefits of city nature are likely substantial.

Fourth, we have demonstrated attention boosts on a 5 min sustained attention task. We do not, however, know how long these benefits last. Further research should examine the longevity of attention boosts from nature micro-breaks, as well as the frequency of breaks required to maintain attention over extended periods of time. Enhancing concentration towards tasks could have follow on benefits including improving performance and mood, and reducing stress (Hartig et al., 2003).

Our study provides evidence that a 40-s view of a flowering meadow green roof can boost multiple networks of attention. We have highlighted the importance of ‘green’ micro-breaks, and highlighted boundary conditions of attention restoration theory. Our research provides further evidence of the effects of nature on cognitive functioning by showing the speed at which attention boosts occur, that different types of non-traditional nature can boost attention, and that this can occur even within a city scene. The argued sub-cortical arousal and cortical attention control benefits of viewing a green roof, and the associated psychological and social effects of viewing nature, provide powerful additional rationales for incorporating more nature in and around cities and workplaces.

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