

## Research paper

## Impact of views to school landscapes on recovery from stress and mental fatigue

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## HIGHLIGHTS

- The effect of window views on attention and stress were tested using randomized controlled experiment.
- Window views to green landscapes promote high school students' attention restoration.
- Window views to green landscapes speed high school students' recover from stress.
- Attention restoration and stress recovery are separate pathways.
- Exposure to daylight alone did not improve student performance.

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## ABSTRACT

Previous research has demonstrated positive associations between the greenness of high school landscapes and school wide academic performance. We do not know, however, if green landscapes cause better performance or if the association between the two is a product of self-selection. If there is a causal relationship, the pathways through which green school landscapes affect student performance remain unclear. We hypothesize that views onto green landscapes help students recover from mental fatigue and stress. To test these hypotheses, we conducted a randomized controlled experiment with 94 high school students at five high schools. Participants were randomly assigned to classrooms without windows or with windows that opened onto a built space or a green space. Participants engaged in typical classroom activities followed by a break in the classroom to which they were assigned. Attentional functioning was measured using Digit Span Forward and Backwards. Physiological stress levels were measured by skin conductance, body temperature, pNN50 (the proportion of the number of pairs of successive NNs that differ by more than 50 ms divided by the total number of NNs) and LF/HF (the ratio between low-frequency peak and high frequency peak). Results demonstrate that classroom views to green landscapes cause significantly better performance on tests of attention and increase student's recovery from stressful experiences. A lack of mediation effect demonstrates that attention restoration and stress recovery are two distinct processes. Implications for school site selection, design and renovation are discussed.

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## 1. Introduction

Context impacts learning. It is well-documented, for instance, that physical characteristics of school environments such as lighting, noise, indoor air quality and thermal comfort, building age and condition all impact learning (Aturupane, Glewwe, & Wisniewski, 2013; Cheryan, Ziegler, Plaut, & Meltzoff, 2014; Roorda, Koomen,

Spilt, & Oort, 2011). There is growing evidence that we have overlooked the impact school landscapes have on student academic performance. The cost of this oversight is that millions of children are trying to learn in settings that may be significantly less supportive than they might otherwise be.

Recent studies examining students' exposure to nature found the amount of vegetation on and surrounding campus significantly predicted school-wide student performance (i.e., standardized test scores, graduate rates) (Matsuoka, 2010; Wu et al., 2014). These exciting findings are correlational and thus the extent to which exposure to green school landscapes causes increased student performance remains unsubstantiated. We also do not know the mechanism or pathways through which green landscapes

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might influence student performance. Finally, if there is a causal relationship, we lack information regarding when the benefits of exposure to green campus landscapes might occur for students. The study reported here is designed to address these questions.

We begin by examining theory and evidence suggesting two possible pathways through which exposure to landscapes might result in better student performance—attention restoration and stress reduction. Next, we report a new study involving a randomized controlled experiment and end by discussing the implications of the findings for a variety of stakeholders.

## 2. Theoretical framework on nature and student performance

### 2.1. The influence of green space on children and adolescents

Exposure to green space has been shown to have a variety of positive impacts on children and adolescents. These benefits include enhanced physical activity and play (Barton, Sandercock, Pretty, & Wood, 2014; Dymont & Bell, 2008), reduced chances of obesity and other chronic diseases (McCurdy, Winterbottom, Mehta, & Roberts, 2010), enhanced mental health and resilience (Chawla, Keena, Pevac, & Stanley, 2014; Corraliza & Collado, 2011; Flouri, Midouhas, & Joshi, 2014; Wells & Evans, 2003), improved environmental awareness (Chawla, 2009; Cheng & Monroe, 2012; Collado, Staats, & Corraliza, 2013; Wells & Lekies, 2006), and enhanced self-discipline and ability to concentrate (Faber Taylor & Kuo, 2009; Faber Taylor, Kuo, & Sullivan, 2002).

In education settings, recent studies have described a restorative effect associated with direct or indirect exposure to trees and other forms of vegetation on students across age groups. For elementary school students, the perceived restorativeness of school playgrounds is positively associated with vegetation volume and naturalness (Bagot, Allen, & Toukhsati, 2015; Collado & Corraliza, 2015). In a quasi-experimental study, middle school landscape renovation that increased the amount of vegetation was associated with reduced stress levels and enhanced psychological well-being (Kelz, Evans, & Röderer, 2013). Real and simulated views of natural elements were positively related to measures of attention and perceived restorativeness of college campus settings (Felsten, 2009; Laumann, Gärling, & Stormark, 2001; Tennessen & Cimprich, 1995). These studies suggest that students show objectively measured and anticipated restoration when exposed to greenness.

Green space offers restorative potentials, but to what extent does exposure to landscapes containing vegetation impact student performance? Two recent studies shed light on this question. One examined the relationship between vegetation condition surrounding schools and school-based student performance on math and English as measured by the Massachusetts Comprehensive Assessment System and found a positive association between vegetation cover and academic performance (Wu et al., 2014). Another study measured high school environments including the amount of vegetation visible from classroom and cafeteria windows, the size of the windows, and the density of vegetation in each part of the campus, to predict student performance (i.e., standardized test scores, graduate rates, percentage of students planning to attend college). The findings demonstrated a positive relationship between nearby nature and school-wide academic performance (Matsuoka, 2010).

Although these two studies reveal a promising association between green campus landscapes and student academic performance, they are cross-sectional, correlational studies that cannot draw conclusions regarding the causal impact of greener campuses

on student performance. Thus, building on previous findings, we conducted a randomized controlled experiment to examine how green space affects academic performance. Why do students perform better when they were exposed to greener views? Two pathways seem most promising.

### 2.2. Possible pathways between landscape and student performance

Two theories have been proposed that might explain the effect of exposure to green landscapes on student performance: Attention Restoration Theory (ART) (Kaplan, Kaplan, & Ryan, 1998; Kaplan, 1995) and Stress Reduction Theory (SRT) (Ulrich et al., 1991).

Sustained attention is the most important resource for learning. For students, inattention often results in academic underachievement (Demaray & Jenkins, 2011; Rapport, Scanlan, & Denney, 1999), and access to nature has been demonstrated as crucial for restoring attentional capacities (Schuttle, Torquati, & Beattie, 2015). Therefore, restored attention may be a pathway through which green landscapes lead to better performance.

ART proposes that people use voluntary control to inhibit distraction and remain focused, and this capacity to remain focused fatigues over time. After a short exposure to a green space, the cognitive capacity to focus attention is renewed because contact with nature enhances the inhibitory mechanism on which directed attention depends (Kaplan et al., 1998; Kaplan, 1995). Exposure to nature has been found to restore the cognitive resources supporting both executive functioning and self-regulation (Kaplan & Berman, 2010), which are also critical to learning.

Stress is predictive of reduced performance for children and adolescents. Studies have repeatedly shown that students who report lower personal and school-related stress attain higher GPAs (Gillock & Reyes, 1999), show more academic achievement (Grannis, 1992), and are less likely to engage in behaviors that lead to lower performance (e.g., truancy, dropping out of school) (Hess & Copeland, 2001). Therefore, reducing the stress that students experience might be a pathway through which green landscapes impact student performance.

SRT proposes that exposure to nature supports psychophysiological stress recovery, resulting in reduced blood pressure and lower levels of stress hormones (Ulrich et al., 1991). Recent studies also show positive physiological responses to nature including better neuroendocrine functioning (Van Den Berg & Custers, 2011), immune system functioning (Li, 2010), meditative brain wave activities (Aspinall, Mavros, Coyne, & Roe, 2013), and recovery from stressful experiences (Jiang, Chang, & Sullivan, 2014a; Jiang, Li, Larsen, & Sullivan, 2014b). A study involving elementary schools in Baltimore, Maryland, reported that students find green schoolyards a safe retreat from stress, because the natural areas allow students to build competence and form supportive relationships (Chawla et al., 2014).

The possible relationship between attention restoration and stress recovery has been mentioned but not empirically tested. One theory is that attentional fatigue is an aftereffect of stress (Ulrich et al., 1991), and therefore the attentional restoration effect is based on emotional and physiological changes. Kaplan (1995), on the other hand, argue that stress can be caused by the human perception of inadequate resources. When one's attentional resources are reduced by a demanding task, an individual's appraisal of inadequacy may trigger physiological stress. To date, however, no research has tested the mediation effect of stress recovery on attention restoration, or vice versa. Therefore, in addition to testing the two potential pathways, we might advance our understanding of the relationship between these two mechanisms by testing the extent to which the relationship between

green campus spaces and attention restoration depends on recovery from stress.

### 2.3. The effect of daylight on student performance

It is possible that the stress recovery and attention restoration effect of a window view, as well as student performance, is influenced by daylight entering the window (Collins, 1976; Plympton, Conway, & Epstein, 2000; Slopach, 2011; Zadeh, Shepley, Williams, & Chung, 2014) rather than, or in addition to, the greenness of the view. For many people, low levels of daylight can lead to seasonal depression, often called seasonal affective disorder (Beauchemin & Hays, 1996). The symptoms of seasonal depression include sadness, anxiety, irritability, loss of interest in usual activities, withdrawal from social activities, and inability to concentrate (American Psychiatric Association, 2013). Clearly, these conditions are not conducive to learning.

Studies of daylighting in schools have demonstrated that full-spectrum daylighting in classrooms can promote overall health, reduce stress hormones, and enhance student performance (Küller & Lindsten, 1992; Nicklas & Bailey, 1997). These studies compared performance of students who learned in classrooms with different skylight and window light conditions. Thus, we wonder, is it enough to have access to daylight in classrooms or do views of green space enhance attentional functioning and help students recover from stressful experiences above and beyond exposure to daylight?

In order to examine the possible underlying mechanisms driving this relationship between campus greenness and student performance, we conducted an experiment using a randomized controlled design. We examined three main hypotheses—that views of green space from classrooms: (1) restores students' attentional functioning; (2) reduces students' stress levels; (3) reduces students' stress levels and restore attentional functioning above and beyond any effect from daylight. We also examine the magnitude and timing of the two effects, as well as the mediation effect of stress in the relationship between window view and attention.

## 3. Methods

### 3.1. Experiment setting and participants

Five public high schools in central Illinois were selected based on the criteria that they contained three classrooms that were identical in terms of room size, window size, lighting and furniture, but different in window views. To increase the generalizability of our findings, we selected two schools that were located in urban areas and three that were in suburban or rural areas. In each of the participating schools, we selected three classrooms for the experiment: a classroom with no windows, a classroom with windows that opened onto a built space, and a classroom with windows that opened onto a green space (Fig. 1). Before the experiment, we arranged the classrooms to ensure similar classroom layout.

Ninety-four high school students (53 female and 41 male) were randomly assigned to one of the three classrooms in the school where they attended. The no window, barren window and green window classroom conditions had 32, 32, and 30 participants, respectively. The experiment was conducted with one student at a time between 9 am and 5 pm on sunny days with room temperatures approximately 70 °F. All rooms had all lights turned on. After giving consent, participants reviewed the inclusion criteria to ensure that they had no major health conditions or drug use that would influence their physiological or cognitive performance.

To account for confounding variables, a general information questionnaire was administered to collect data about participants' age, gender, race, grade, health information, self-reported chronic stress levels, self-reported chronic mental fatigue, and preference for their school landscape.

### 3.2. Procedure

Each participant was randomly assigned to one of the three classrooms and completed the experiment with two examiners in the room. No other students or teachers were present during the experiment. All examiners were trained to follow the same experimental procedure, and they rotate to administer the three conditions. Students were instructed to sit in seats with identical orientation and distances to a window or, in rooms without windows, to the wall. To simulate classroom activities and induce moderate levels of stress and directed attention fatigue, all participants underwent a modified Trier Social Stress Test (TSST) procedure (Kirschbaum, Pirke, & Hellhammer, 1993). First, participants had a 5-min rest (time 1: baseline). Then, they engaged in 30 min of classroom activities that included a proofreading task to find given sequences of letters in a page of random English letters, a speech task in which they were instructed to talk in front of two examiners about their dream job, and a subtraction task in which they were given a four-digit number and asked to subtract 16 from that number, and then to continue subtracting 16 from each subsequent answer for five full minutes (time 2: class activity). They then had a 10-min break during which they remained seated and awake in the classrooms (time 3: break). Questionnaires and attention tests were administered at each time period.

### 3.3. Constructs and measures

#### 3.3.1. Attention

**3.3.1.1. Subjective attention.** Participants' baseline attentional functioning was assessed using a Visual Analogue Scale (VAS) questionnaire. VAS has been tested for construct validity and reliability, and has been shown to be well suited for the clinical assessment of self-reported psychological conditions (Lesage, Berjot, & Deschamps, 2012). The VAS consisted of a 10-cm horizontal line. The left end of the line was marked "not at all" (0) and the right "extremely" (100). After hearing the instructions, participants placed a mark (X) on the line indicating the degree of mental fatigue they felt at that moment. By measuring the distance from the left end of the scale to the mark, we identified the value for the self-reported attention measure.

**3.3.1.2. Objective attention.** Participants were also asked to take the Digit Span Forward (DF) and the Digit Span Backward (DB) tests (Wechsler, 1981) of attentional functioning twice—once after the classroom activities, and once after the break. The DSF and DSB tests required participants to repeat increasing lengths of digit sequences in normal and reversed order until they make two consecutive failures. The tests have been used in a number of studies to assess attentional capacity, short-term memory and working memory (Yudofsky & Hales, 2008). We created a summary score for DSF and DSB to be used in the statistical analyses.

#### 3.3.2. Stress

**3.3.2.1. Subjective stress.** Participants' baseline stress level was also assessed using a Visual Analogue Scale (VAS) questionnaire assessing the degree of stress they felt at that moment.

**3.3.2.2. Objective stress.** To record physiological measures of stress, participants were equipped with wrist and finger receivers of Electrocardiography (EKG), Blood Volume Pulse (BVP), Skin



**Fig. 1.** Examples of classroom window view conditions: no window (left), windows opened on to built spaces (middle), and windows opened on to green space (right).

Conductance Level (SCL) and body temperature (BT) throughout the experiment by the clinical biofeedback device Procomp Infiniti Physiological System. These measures are the most widely employed methods for measuring physiological stress, and are often used together in research related to exposure to nature and stress recovery (Jiang et al., 2014a; Chang, Hammitt, Chen, Machnik, & Su, 2008).

**Heart rate measurement.** Heart rate variability (HRV) was extracted from EKG and BVP data. Raw EKG data were reviewed to correct missed beats and extra beats. HRV represents the variation in the time interval between one heartbeat and the next (inter-beat interval), and has been shown to be one of the most reliable indicators of stress (Task Force of the European Society of Cardiology, 1996). The inter-beat interval (IBI) data were examined with Kubios HRV analysis software (University of Kuopio, Kuopio, Finland) to detect artifacts. Cubic spline interpolation was applied to replace missing IBI's. Data were also detrended using the smoothness priors method (Tarvainen, Ranta-Aho, & Karjalainen, 2002). Time-domain measure pNN50 and frequency-domain measure LF/HF ratio were calculated at three times during the experiment. NN50 measures the number of pairs of successive normal inter-beat intervals that differ by more than 50 ms, with a smaller value indicating more stress and anxiety. pNN50 is the percentage of NN50 count within the total RR interval. LF/HF ratio is the ratio between the LF band power (0.04–0.15 Hz) and the HF band power (0.15–0.4 Hz), and a larger value indicates a hyper sympathetic nervous system which is related to increased acute stress and anxiety (Malik et al., 1996).

**Skin conductance level (SCL) and body temperature (BT) measurement.** Skin conductance (SCL) and body temperature (BT) have also been widely used to measure mental stress in laboratory and real life settings (Healey & Picard, 2005). SC and BI were collected with a sampling rate of 2048 measurements per second. Raw SCL and BT data were processed to remove noise.

### 3.3.3. Control variables

Since students' chronic levels of stress, mental fatigue and landscape preference might influence our acute measures of stress levels and attentional functioning, we included Likert scale questions assessing chronic stress, chronic mental fatigue and the extent to which participants preferred their campus landscape.

## 4. Results

Results are presented in four sections. First, we compare the baseline attention and stress levels among the three window-view groups to ensure there are no pre-treatment group differences. Second, we explore the effect of window view on students' ability to pay attention during class activities and after the break. Third, we examine the same window-view effects on students' stress levels during class activities and after the break. In the last section, we investigate the extent to which stress recovery mediates the relation between green view and attention restoration.

### 4.1. Baseline attention and stress

Were there differences among the baseline levels of attention and stress for students who were randomly assigned to the three window conditions? There are no significant differences in the baseline attentional functioning levels ( $F = 0.54, p = 0.59$ ), stress levels ( $F = 0.98, p = 0.38$ ), chronic mental fatigue ( $F = 1.33, p = 0.27$ ), chronic stress ( $F = 1.13, p = 0.33$ ), or landscape preference ( $F = 0.02, p = 0.98$ ) measures across the three groups at the beginning of the experiment. Overall, students' stress levels increased during the class activities and decreased after the break. Their attentional capacity declined during the class activities and rebounded after the break.

#### 4.2. Effect of window view on attentional functioning

To what extent did the window view effect students' attentional functioning during class activities and after the break? To answer this question, we created a summary attention score using two objective measures of attention, digits forward and digits backward, and examined the repeated-measures ANOVA result during the baseline, after class activities and after the break.

Did the window view affect attention? Yes, a repeated-measures ANOVA with window view as the between-subject factor and class activity and break as the within-subject factors revealed both significant main effects and an interaction. Students' capacity to pay attention decreased during class activities and increased after the break ( $F_{1,90}(\text{time}) = 10.50, p < 0.01, \eta^2 = 0.10$ ). Second, the window views differed in terms of their impact on student attentional functioning ( $F_{1,90}(\text{treatment}) = 4.43, p < 0.05, \eta^2 = 0.09$ ). Third, the recovery effects of performing the activities and having a break differed based on the window view ( $F_{2,90}(\text{time} \times \text{treatment}) = 11.14, p < 0.001, \eta^2 = 0.20$ ).

Did the difference in attentional capacity occur after class activities, or after the break? To answer this question, we conducted univariate ANOVAs examining the impact of window views at the end of class activities and after the break. There was no difference among the groups at the end of the class activities ( $F_{2,90}(\text{activity}) = 0.51, p = 0.60, \eta^2 = 0.01$ ), but there was a significant difference at the end of break ( $F_{2,90}(\text{break}) = 8.98, p < 0.001, \eta^2 = 0.17$ ) (Fig. 2). The attentional capacity in the green window view condition was 14.33 percent higher than the other two conditions combined.

Which window view condition caused the attention restoration effect? To answer this question, we made pairwise comparisons using Tukey's HSD (Tukey, 1949). The results demonstrate that after the break, the mean attention score for the green window view condition was significantly greater than the barren condition ( $p < 0.001$ ) and the no window condition ( $p < 0.01$ ). The barren and no window groups, however, showed no difference in attentional functioning after the break ( $p = 0.69$ ). Overall, students in the green window view condition demonstrated a 13.12 percent increase in attentional functioning.

What was the magnitude of the attention restoration effect after controlling for confounding variables? To answer this question, we regressed the change in attention scores (after break scores minus after class activity scores) onto the window view conditions (Table 1). The models controlled for demographic factors, chronic stress, chronic mental fatigue, and landscape preference. Taken together, these factors explained 18 percent of the variance in individual attention restoration (Model 1). After adding in classroom window view, the model improved significantly ( $p < 0.001$ ) and explained 31 percent of the total variance (Model 2). Students with green window views achieved attentional functioning restoration of 0.7 units higher than their peers who were randomly assigned to a barren window view, after controlling for the other variables. But the difference in attention restoration between the no window condition and the barren condition was not significantly different ( $p = 0.67$ ).

#### 4.3. Effect of window view on stress

Does the window view have a significant effect on student's stress level during class activity and after the break as on attention restoration? To answer this question, we created a standardized summary physiological score (Cwir, Carr, Walton, & Spencer, 2011; Jiang et al., 2014a; Rosenthal & Rosnow, 1991; Rutledge & Linden, 1998) from skin conductance (SC), body temperature (BT), percentage of NN50 (pNN50) and ratio between low-frequency peak and

high frequency peak (LF/HF) and performed repeated-measures ANOVA.

The repeated-measures ANOVA results show the effect of window views at different points in the experiment. First, similar to the attention results, students' stress levels changed significantly during class activity and after the break ( $F_{1,84}(\text{time}) = 19.6, p < 0.0001, \eta^2 = 0.19$ ). Considering all time periods, there was no significant difference in stress across the window view conditions ( $F_{1,84}(\text{treatment}) = 1.93, p = 0.15, \eta^2 = 0.04$ ). There were, however, different changes in stress levels across the three window view conditions, though the effect size was small and the effect was only marginally significant ( $F_{2,84}(\text{treatment}) = 2.73, p = 0.07, \eta^2 = 0.06$ ) (Fig. 3).

Because the time effect suggested stress recovery and the interaction effect was marginally significant, we compared the changes in stress levels (summary of changes of the four stress indicators) during class activities to the period immediately after the break across the groups using univariate ANOVA. The result showed a significant treatment effect in stress recovery ( $F_{2,84}(\text{stress recovery}) = 3.69, p < 0.05, \eta^2 = 0.08$ ). Overall, the effect of window view on stress was similar to the pattern of change in attentional capacity, but the effect size was smaller.

To what extent did classroom window view predict stress recovery above and beyond demographic factors and baseline conditions? To answer this question, we regressed the summary stress recovery scores onto the environmental window conditions (see Table 1). Demographic factors, chronic stress, chronic mental fatigue, and preference explained 10 percent of the variation in stress reduction at the end of the break (Model 3). After adding in classroom window condition, the model significantly improved ( $p < 0.05$ ) and explained 17 percent of the total variance (Model 2). Stress reduction in a green condition was 1.36 units higher than that of the barren condition. But the comparison between no window and barren conditions was only marginally significantly different ( $p = 0.07$ ).

#### 4.4. Did stress recovery mediate the relationship between window view and attention?

In the analyses above, we found that window view caused significant variations in both stress recovery and attention restoration. It is possible, therefore, as some have suggested (Ulrich et al., 1991) that the impact of window view on attention restoration is mediated by stress recovery. That is, the effect of window view on attention restoration may occur *through* stress recovery. If this were the case, stress recovery should be systematically associated with attention restoration. And adding in stress recovery in the regression model of window view predicting attention restoration would make the attention pathway completely or partially disappear. To test this possibility, we conducted a one-tailed Pearson Correlation and found that stress recovery and attention scores are not correlated ( $r = 0.08, p = .23$ ). Thus, in this study, stress reduction did not mediate the relationship between window view and attention restoration.

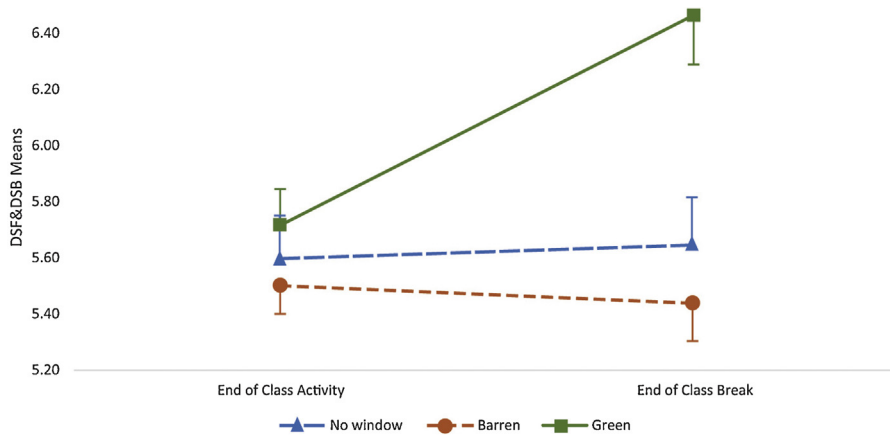
### 5. Discussion

In this study, 94 students from five high schools were randomly assigned to classrooms without windows, with windows that opened on to built space, and with windows that opened on to green spaces. Students in the green window view condition scored significantly higher on tests of attentional functioning and recovered significantly faster from a stressful experience than their peers who were assigned to rooms without views to green spaces. Accounting for confounding variables, the findings establish

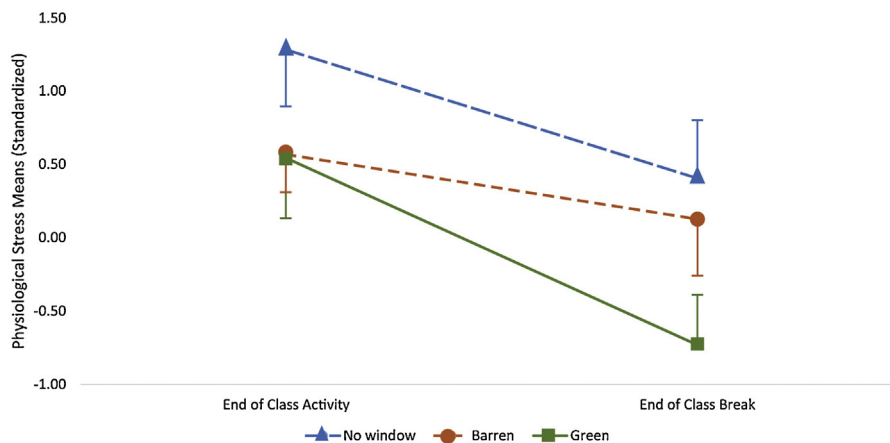
**Table 1**  
Regression analysis for window view conditions predicting attention restoration and stress recovery.

Variables	Attention model				Stress model			
	Model 1		Model 2		Model 3		Model 4	
	B	SE	B	SE	SE	SE	B	SE
Intercept	-0.13	1.56	-0.10	1.46	-3.29	4.36	-4.26	4.27
Demographics								
Male	0.48**	0.17	0.46**	0.16	-0.19	0.48	-0.21	0.46
Age	0.04	0.09	0.00	0.09	0.15	0.26	0.13	0.26
Race								
African American	-0.01	0.21	0.16	0.20	-0.72	0.59	-0.42	0.59
Hispanic	-0.01	0.40	-0.10	0.38	0.49	1.23	0.21	1.21
Asian and Pacific Islander	-0.21	0.40	0.06	0.38	-0.39	1.08	-0.04	1.07
Other	-0.89*	0.37	-0.59**	0.35	-0.75	1.11	-0.13	1.10
Other controls								
Chronic stress level	0.11	0.12	0.10	0.11	0.40	0.34	0.40	0.33
Chronic attentional problems	-0.31*	0.17	-0.20	0.16	-0.65	0.47	-0.48	0.46
Landscape preference	-0.01	0.13	0.02	0.12	0.54	0.35	0.61*	0.34
Treatment (barren view as reference)								
No window			0.08	0.18			0.98*	0.54
Green view			0.70***	0.20			1.36*	0.57
Stress level change								
$R^2$	0.18		0.31		0.10		0.17	
$\Delta R^2$			0.13***				0.07*	

+  $p < 0.1$ .  
\*  $p < 0.05$ .  
\*\*  $p < 0.01$ .  
\*\*\*  $p < 0.001$ .



**Fig. 2.** Attention scores at the end of class activity and break (Means and SE).



**Fig. 3.** Physiological stress at the end of class activity and break (Mean and SE).

a causal relationship: green views produced better attentional functioning and greater recovery from stress. We found no beneficial impact of daylighting alone. Finally, there was no evidence that stress mediated the relation between view to green landscapes and attention restoration, suggesting these are two distinct pathways influencing students' psychological and cognitive functioning.

### 5.1. Contributions

This is the first study to use a randomized controlled experimental design to examine the effect of views to green campus landscapes on students' attentional functioning and stress levels during class activities and breaks. Since sustained attention and free of stress have been proved to be critical for learning, our findings suggest the possible mechanism between greener campus and better student performance: green views promote attention restoration and recovery from stressful experiences. In this experiment, at the end of the class activities, there were no differences among the students in the three window view conditions with respect to attentional functioning or stress. But by the end of the break, students in the green window view condition performed significantly better on standard tests of attention and showed significantly greater stress recovery than their peers who were assigned to classrooms without a green view.

Why did a green view not result in higher attentional functioning and lower stress during classroom activities of the experiment? An explanation can be found in Kaplan's original article on ART which states that there are two ways of paying attention: voluntary and involuntary attention (Kaplan, 1995). During class activities, in order to focus their attention, students must ward off distractions by inhibiting stimuli in their surroundings and thoughts that compete for their attention. This inhibiting mechanism gets fatigued after prolonged mental effort (Kaplan & Berman, 2010). During the break, in the presence of green spaces visible through a window, involuntary attention is automatically activated and after a short period of time, as the inhibitory mechanism rests, a student's ability to focus attention is restored.

This study also reveals that exposure to nature impacts cognitive performance directly, rather than through the mediation effect of stress. Although both processes occurred during this experiment when students had window views of a green space, the changes in attention and stress were not correlated.

Other studies have hinted at such a finding. For example, in an experimental study, the group assigned to view a nature video showed significant improvements in stress recovery but no improvement in attention scores (Laumann, Gärling, & Stormark, 2003). A study comparing the impact of walks in nature and urban environments reported significant impacts of the walks on physiological stress but not attention (Hartig, Evans, Jamner, Davis, & Gärling, 2003). The only previous study examining the association between changes in attention tasks and mood states revealed no correlation between the two, suggesting the cognitive and affective benefits from nature are due to different processes (Berman et al., 2012).

Attention restoration grows from the effortless attention-drawing character of nature (soft fascination) (Kaplan & Kaplan, 1989), which restores humans' ability to pay attention. Stress recovery is likely due to humans' readiness to respond affectively and physiologically to nature (Ulrich, 1993). The major difference of the two pathways is that attention restoration is based on cognition and the effect is through human cognitive operations, whereas stress recovery is based on affect and the effect is through physiological responses to stress.

The relationship between attention and stress is complex (Kaplan, 1995; Ulrich, 1993). Although the findings presented here demonstrate that stress and attention can occur independently, it

is easy to imagine circumstances in which chronic stress can lead to attentional fatigue. Think, for instance, of a mother living in a dangerous setting who is constantly on the lookout for threats to her children. This mother is at risk of suffering chronic mental fatigue (Kuo, 2001). It also seems likely that mental fatigue can lead to stress—especially in anticipation of inadequate mental resource (Kaplan, 1995). Ulrich goes one step further, however, and proposes that positive mood states can lead to attention restoration (Ulrich, 1993). The empirical findings testing this possibility are mixed. One study reported poorer cognitive control in positive mood states (Oaksford, Morris, Grainger, & Williams, 1996), while others have reported that positive mood states might promote attentional functioning associated with specific tasks that require creativity but not in tasks that require more focused attention (Ochsner & Gross, 2005; Phillips, Bull, Adams, & Fraser, 2002).

A stressful experience can even enhance attention under certain circumstances. The environmental rejection theory (Lacey, 1967; Lacey & Lacey, 1974, 1978) suggests that stressful mental tasks such as subtraction can accelerate heart rate, and in turn enhance one's capacity to resist distracting environmental stimuli (in other words, enhance directed attention).

Taken together, the findings presented in this paper and those from previous research suggest there are separate, demonstrated pathways from nature to enhanced attentional functioning and reduced stress, but inconclusive interrelationships between attention and stress.

In this study, we found that exposure to daylight had no impact on attentional functioning or stress recovery. That is, there were no statistically different outcomes between the classrooms with no windows and those that had window views that allowed natural daylight in but that looked out to built settings devoid of vegetation. These findings indicate that daylight is not a major factor underlying the relationship between window view and reduced stress and better attentional functioning. Thus, we should use caution when reviewing evidence on daylight and student performance or stress recovery, because the presence of green window views could be driving the different outcomes between window lighting conditions and no window conditions (Plympton et al., 2000; Slopack, 2011).

### 5.2. Implications

The evidence presented here points to environmental factors that designers, planners, and policy makers can manipulate in order to enhance students' well-being and their likelihood of learning. We discuss the implications of these findings below.

#### 5.2.1. School site selection

For planners working to identify sites for new schools, the result here suggest that sites that already have trees and other forms of vegetation are likely to have positive impacts on student learning. In the last few decades, there has been a dramatic shift in the location of high schools in North America. Whereas almost all high schools more than 50 years old are located in urban and suburban areas, almost all newer high schools (those less than 30 years old) are located at the rural-urban fringe or in rural areas. The hidden cost of siting schools on what was recently an agricultural field is that the lack of nearby trees will likely have negative consequences for learning. One easy solution is to be sure that a portion of the school design and development budget is reserved for site improvements that include planting a considerable number of trees on the site.

#### 5.2.2. School ground and building design and renovation

Architects should work to ensure that every classroom has views to green space. Landscape architects should consider the locations

of classroom, cafeteria and hallway windows in the development of their campus designs. Historically, campus design has been approached from the perspective of visitors to schools—landscape features are designed to enhance the view to the school and give visual identity to the main entrance. The findings of this study, however, indicate that campus landscapes should serve more purposes than merely aesthetic appeal, and that designers should also consider the access to green space and green views from the angle of students and teachers who interact with the spaces on daily basis, especially those spaces that students and teachers interact with during their breaks. In addition to classroom views, views to green landscapes from hallways and the cafeteria seem particularly important. Providing views to green space in such areas will help students recover from mental fatigue and stress during their breaks and prepare students for their next class. Similarly, during renovations, designers should pay more attention to greening efforts on school grounds especially in areas where student activities and recess take place.

The views from classroom and cafeteria windows should be filled with natural features such as trees and shrubs. Classroom window views of large expanses of parking lots and athletic fields lacking natural elements should be minimized or screened by vegetation. Compared to most of the interventions aimed at relieving stress (e.g., emotional skill building, anger management, positive behavior programs), placing trees and shrubs on the school ground is a modest, low-cost intervention that is likely to have long-lasting effects on generations of students.

Further, our findings suggest a 10-min break would suffice in restoring students' attentional capacities and help them recover from stressful tasks. School bell schedule should be designed to include short break periods to allow students to restore their attentional capacities.

### 5.3. Limitations and future research

To assess the effect of window view on student's stress level and attentional capacity, we carefully controlled a number of factors including setting, classroom activities, and break conditions (e.g., students remained seated during the break). This design, which allowed us to ensure that all participants received the same treatments, increased the internal validity of this work. One limitation of such an approach, however, is that we could not take into account students' interactions, students' physical activities and their immersive experiences out on the school ground during the break, or their exposure to green space during physical education classes or after school. This limits the ecological validity of the findings presented here. Studies have demonstrated how immersive experiences in green school grounds help students recover from stress, build coping strategies, and form supportive social networks (Chawla et al., 2014). Exercise in green space in school may also help students negotiate stress, regain attentional capacity and enhance mental health (Burdette & Whitaker, 2005). Future studies should examine how physical exposure to green schoolyards affect students' stress levels and attentional functioning. Future research might measure the combined impact of having green views from the school and green immersive experience, such as exercises on the school ground, on student performance.

The current study under-represents both the academic demands placed on students and the extent to which students may be exposed to green settings. A 40-min experimental period far under-represents the academic and non-academic events that occur during an academic year that influence student's stress and attentional functioning. And the school ground is only one part of students' daily exposure to landscapes and thus cannot represent the variety or extent of landscapes to which students are exposed. Thus, future studies should expand the geographic and

temporal aspects of landscape exposure and examine how other spaces impact student's psychological well-being and academic performance.

We made sure that the experiment resembled typical learning situations by including a 10-min break in the study design. Most high schools in the US have breaks of 10 min or less. Clearly, a break of 10 min was long enough to demonstrate the impact of green views on attention and stress. Would a longer break have shown a larger effect on stress recovery? Would increasing the frequency of breaks also show an effect? What is the effect of the interaction between the duration and frequency of breaks with green view on students' stress recovery and attention restoration? Future research should examine these possibilities.

It is also possible that the relationship between green views and stress recovery is not linear. That is, in the first few minutes of a green view, stress recovery may be slow, but over time, recovery may speed up. To our knowledge, no research has established the time-course of stress recovery associated with green views. This is a promising area for future research.

We found no differences in stress recovery or attention restoration for students randomly assigned to classrooms without windows and to classrooms with windows that allowed sunlight to enter but did not provide views to vegetation. We did not measure the intensity of sunlight or make any effort to ensure that the sunlight in either the barren window or green window condition was at all similar. This presents some slight threat to internal validity. Future research might explore the impact of varying levels of sunlight under barren and green conditions on stress recovery and attention restoration.

This study examined the effect of classroom window views on high school students. Although this study did not measure academic performance and therefore cannot fully explain the pathway from greenness to academic performance, the findings suggest that stress recovery and attention restorations are pathways through which school landscapes influence student performance. Future study can test the mediation effect of attention and stress on academic performance directly. The findings add to the evidence demonstrating that green views have powerful effects on the productivity of students at various ages (Faber Taylor & Kuo, 2009; Matsuoka, 2010; Wu et al., 2014). Since cognitive functioning is critical to understanding, learning and performing different types of activities, views to green landscapes may also impact the productivity of workers (Bringslimark, Hartig, & Patil, 2007; Bringslimark, Patil, & Hartig, 2006). These pathways suggest rich possibilities for future studies.

## 6. Conclusions

We close by noting the importance of enhancing students' psychological and cognitive health by providing classrooms with green window views. This study demonstrated that classroom views to green landscapes have significant, positive impacts on recovery from stress and mental fatigue. These findings can provide guidance to parents, teachers, school administrators, architects, landscape architects, planners and policy makers interested in creating more supportive environments for learning.

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