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# Impact of Urban Nature on Executive Functioning in Early and Middle Childhood

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## Abstract

According to attention restoration theory, directed attention can become fatigued and then be restored by spending time in a restorative environment. This study examined the restorative effects of nature on children's executive functioning. Seven- to 8-year-olds (school aged,  $n = 34$ ) and 4- to 5-year-olds (preschool,  $n = 33$ ) participated in two sessions in which they completed an activity to fatigue attention, then walked along urban streets (urban walk) in one session and in a park-like area (nature walk) in another session, and finally completed assessments of working memory, inhibitory control, and attention. Children responded faster on the attention task after a nature walk than an urban walk. School-aged children performed significantly better on the attention task than preschoolers following the nature walk, but not urban walk. Walk type did not affect inhibitory control or verbal working memory. However, preschoolers' spatial working memory remained more stable following the nature walk than the urban walk.

**Keywords:** attention, working memory, attention restoration theory, nature, cognition, preschoolers

Today, children are spending less time in natural environments than was common in the past (Clements, 2004; Hofferth, 2009; but see also Larson, Green, & Cordell, 2011). This decrease in time spent in nature may have important implications for the health and well-being of children. A growing body of evidence suggests that spending time in natural environments can benefit children's attention. For example, parents of children diagnosed with attention deficits (Attention Deficit Disorder or Attention Deficit Hyperactivity Disorder, ADD/ADHD) reported that their children exhibited fewer symptoms of ADHD after their children engaged in outdoor activities in natural environments compared with indoor environments (Kuo & Faber Taylor, 2004), and even compared with outdoor activities in built environments (Faber Taylor & Kuo, 2011). Similarly, children aged 7 to 12 years diagnosed with ADD or ADHD demonstrated improved attention as assessed by the Digit Span Backwards (DSB) after a 20 min walk in a park compared with a 20 min walk in an urban area. The effect size of the nature walk was comparable with the reported effect size of methylphenidate, a commonly prescribed medication for ADD/ADHD (Faber Taylor & Kuo, 2009).

Although much of the experimental work with children in this area has been with children diagnosed with ADHD, some research suggests that the beneficial effects of nature on children's cognitive functioning are not limited to those diagnosed with attention deficits. Low-income girls 7 to 12 years of age performed better on measures of concentration, inhibitory control, and delay of gratification when their apartment windows had more natural views than those without such views (Faber Taylor, Kuo, & Sullivan, 2002). Likewise, parents of children moving from homes with "less natural" surroundings to "more natural" surroundings reported fewer symptoms of ADHD in their children post-move than prior to the move (Wells, 2000). Similarly, preschool children with daily access to a more natural outdoor area demonstrated more focused attention according to their teachers than children with a man-made playground devoid of natural elements (Grahn, Martensson, Lindblad, Nilsson, & Ekman, 1997; Martensson et al., 2009). These findings transcend U.S. culture and context. A study of children in the United Kingdom reported that frequent use of parks and playgrounds was related to decreased hyperactivity (Flouri, Midouhas, & Joshi, 2014). In addition, a study in Munich found that the closer the nearest urban green space was to a child's home, the lower their symptoms of hyperactivity/inattention (Markevych et al., 2014). In addition, a study in Barcelona found that time spent in natural areas was negatively associated with ADHD symptoms (Amoly et al., 2014).

These studies are based on attention restoration theory (ART), which posits that humans have two distinct attentional systems: "voluntary"

(James, 1892) or “directed” attention (Kaplan, 1995); and “involuntary” attention (James, 1892) or “fascination” (Kaplan, 1995). We will use the term “directed attention” to refer to the first attentional system, which requires effort to sustain a specific focus and related activity as well as to inhibit attention toward potential distractions (Kaplan, 1995). Because of the effortful nature of directed attention, it is susceptible to fatigue. The second attentional system is deployed when environmental stimuli are intrinsically interesting, and therefore requires less effort. We will use the term “fascination” in reference to the second attentional system, owing to the inherently compelling nature of activities and environments that elicit this less effortful form of attention. ART posits that when the directed attentional system is fatigued, providing an opportunity to deploy the less effortful fascination system can allow the directed attentional system time to recover. Natural environments appear to offer such an opportunity because they are dynamic, stimulating, and complex (Kaplan, 1995). Other researchers have examined improved functioning after exposure to natural environments from the perspective of Stress Recovery Theory (SRT; Ulrich, 1981; Ulrich et al., 1991). SRT posits that exposure to natural environments can lead to improved performance on assessments of attention and cognition through enhancing positive mood, which is known to enhance attention and memory.

Several studies have examined the potential restorative effects of natural environments on attention using a paradigm in which participants complete tasks designed to fatigue directed attention (a “cognitive load” phase), then engage in activities that are hypothesized to elicit fascination, and finally complete tasks that again require directed attention. In the third phase of the paradigm, better performance on directed-attention tasks following exposure to a hypothesized restorative environment than following exposure to a nonrestorative environment is considered to be a measure of whether or not attention has recovered. Therefore, performance provides evidence of the extent to which the rest activities or environments are restorative. Because of the relative dearth of recent empirical research on children, we include research on both adults and children in our review. Research using this threephase paradigm has demonstrated directed-attention recovery in adults after a nature walk compared with an urban walk or reading magazines (Hartig, Mang, & Evans, 1991). A similar study reported that adults who walked in an urban environment declined in attentional performance while adults who walked in a natural area maintained attentional performance (Hartig, Evans, Jamner, Davis, & Garling, 2003).

Researchers have reported better performance on attention tasks when adults have a natural view from a window, compared with a built view (Kuo, 2001; Tennessen & Cimprich, 1995) or after viewing photos of natural

settings compared with built settings (Berto, 2005). The hypothesized causal process was that in the natural scene condition, directed-attention resources were not required to suppress distracting stimuli. Similarly, Berman, Jonides, and Kaplan (2008) reported improvements in DSB and executive attention after viewing photos of natural scenes. Berman et al. also reported greater improvement in attention (DSB) and mood for adults after walking in a natural versus built setting, but mood was not correlated with DSB. Data were collected during all four seasons, and the authors found no effect of season on attention or mood. Other studies have also found that adults report more positive affect after exposure to natural photos, video, or actual environments than after exposure to photos or video of built environments or actual built environments (Ulrich, 1981; van den Berg, Koole, & van der Wulp, 2003). Studies of children have found lower stress in those exposed to "greener" spaces (Kelz, Evans, & Röderer, 2015; Wells & Evans, 2003).

In summary, several studies of children and adults have yielded evidence of benefits of exposure to nature on attention. Studies have varied in design (correlational, quasi-experimental, and experimental) and exposure to nature (e.g., window views, assessment of "nearby nature," presentation of photos or video of natural settings, parent reports of activities, and nature walks). Children's attention has been measured through parent or teacher reports (Faber Taylor & Kuo, 2011; Faber Taylor et al., 2002; Kuo & Faber Taylor, 2004; Martensson et al., 2009; Wells, 2000) and direct assessments of children (Faber Taylor & Kuo, 2009). Benefits have been observed for children with and without diagnosed attention disorders.

## **Dimensions of Cognition Influenced by Natural Environments**

Although there has been a considerable amount of research examining how attention varies as a function of exposure to natural environments, dimensions of cognition other than attention may be similarly affected. For example, Miyake and colleagues (2000) proposed that directed attention is a domain-free cognitive process that is involved in most executive functions (EF). Although there are various definitions of EF, most agree that EF involves cognitive control processes such as mental set shifting or attentional shifting, working memory or updating working memory, inhibitory control, and planning that allow for goal-directed behavior (Miller et al., 2012; Miyake et al., 2000). Kaplan (1995) argued that attention functions as a resource, and when it is depleted, other processes such as inhibition and working memory are also compromised because they depend on attention:

Directed attention is important because of the central role of selectivity in human information processing, and because of the significance of inhibition in managing behavior ... As the weak link in the chain, it is a highly likely cause of incompetent or inappropriate behavior. (p. 178)

Several measures of attention used in previous research (Faber Taylor et al., 2002; Faber Taylor & Kuo, 2009) assess additional dimensions of EF. For example, those used by Faber Taylor et al. (2002) to assess directed attention (they called "concentration") involved working memory and inhibitory control (Symbol Digit Modalities Test; DSB; Necker Cube Pattern Control task) in addition to directed attention. When choosing measures, researchers should be cognizant of which dimensions of cognitive functioning are being assessed due to the fact that many forms of cognitive functioning seem to affect and/ or rely on other forms. For example, working memory (e.g., spatial, verbal, or object working memory) is an EF that relies on attention and inhibitory control. Deficits in either attention or inhibitory control are generally associated with deficits in working memory (e.g., Roderer, Krebs, Schmid, & Roebbers, 2012; Sowerby, Seal, & Tripp, 2011). It is important to examine multiple dimensions of attention and EF to determine if they are differentially influenced by exposure to nature as reported by Berman et al. (2008), who found that their participants only improved in the executive attention portion of the Attention Network Test after exposure to nature and not the alerting or orienting portions of the measurement.

In addition, cognitive capacities undergo rapid development during early childhood, and there is evidence that different cognitive processes mature at different rates. Between 3 and 5 years of age, children demonstrate rapid improvements on inhibition and delay of gratification tasks (Diamond & Taylor, 1996; Kochanska, Murray, & Harlan, 2000). The executive attention network undergoes rapid development from approximately 2 to 7 years of age (Rueda, Posner, & Rothbart, 2004). Directed attention emerges during infancy (see Colombo & Cheatham, 2006, for a review) but changes substantially between 2 and 6 years of age (e.g., Fisher, Thiessen, Godwin, Kloos, & Dickerson, 2013; Ruff, Capozzoli, & Weissberg, 1998), such that older children are able to sustain their directed attention significantly longer. For example, Ruff et al. (1998) found a significant increase from 2½ to 4½ years of age in the amount of time children focused their attention on a puppet show.

Considering the rapid developmental changes in attention across early and middle childhood, other forms of executive functioning may also prove to be more difficult for younger children in comparison with older children and adults. Carlson (2005) examined children 2 to 6 years of age using a

variety of EF measures and reported that tasks involving a combination of inhibition and working memory were the most difficult at every age, which may explain why the only experimental study to date examining changes in EF performance in 5-year-olds as a function of nature exposure via slide show reported no significant differences (Kidwell, 2012). The measures used in the study, the Hearts-and-Flowers computer task and the Head-Toes-Knees-Shoulders task, involve both inhibition and working memory (Kidwell, 2012). Therefore, these tasks may have been too challenging for preschoolers to show an effect of nature exposure. Consequently, the choice of tasks may be especially important for assessing the influence of nature on the executive functioning of preschool-aged children.

## Goals of the Current Study

The current study expands on the literature by including younger children, examining sex differences, testing typically developing children, and measuring multiple dimensions of executive function. Although there have been correlational studies with preschool children (Grahn et al., 1997; Kuo & Faber Taylor, 2004), no experimental research has been published on the potential restorative effects of natural environments on attention or other cognitive processes in children younger than 7 years of age. The only experimental study that included young children, Kidwell (2012), is an unpublished master's thesis. To address this gap, the current study included 4-, 5-, 7-, and 8-year-old children to determine whether the more limited attentional processes of younger children also benefit from exposure to natural environments.

In addition to varying across ages, the influence of environments on attention and EF may vary by gender. For instance, Faber Taylor and colleagues (2002) reported that girls, but not boys, with a more natural view from home performed better on assessments of concentration, impulse control, and delay of gratification. Several studies did not report analyses of sex differences (Faber Taylor & Kuo, 2009; Faber Taylor, Kuo, & Sullivan, 2001; Kidwell, 2012; Wells, 2000), and two studies reported no gender differences (Faber Taylor & Kuo, 2011; Kuo & Faber Taylor, 2004). In early childhood, the developmental trajectory of some aspects of executive function varies by sex (Vuontela et al., 2003). For example, Vuontela and colleagues found that 6- to 8-year-old girls were more accurate in working memory tasks than were boys; however, there were no significant sex differences at 11 to 13 years of age. Sex differences in the development of EF could result in EF being differentially influenced by exposure to nature in boys and girls. Therefore, because of potential sex differences in performance and because previous research examining sex differences is inconclusive, this



study examined whether effects of natural environments on the restoration of attention and other EF varied by the sex of the child.

In addition to the lack of research examining age and sex differences, research examining the benefits of exposure to nature for children without attention deficits is also limited. A few previous studies have reported benefits to attention and EF for children not diagnosed with attention deficits (Dadvand et al., 2015; Faber Taylor et al., 2002; Grahn et al., 1997; Wells, 2000). Two studies compared performance by exposure to nature near children's homes (Faber Taylor et al., 2002; Wells, 2000), and one compared performance by exposure to nature in preschool programs (Grahn et al., 1997; although, see Kelz et al., 2015, for no effect of a greener school yard). One recent study measured the associations between exposure to greenness at home and school and the change in working memory and attention over the course of a year (Dadvand et al., 2015). Only one published study, however, used an experimental design (Faber Taylor & Kuo, 2009), and the study only included children diagnosed with attention deficits. Therefore, the current study builds on previous work by investigating the potential restorative effects of natural environments on the executive functioning of typically developing children (children not diagnosed with attention deficits or another developmental challenge) using a within-subjects experimental design.

We examined three dimensions of EF: (a) directed attention; (b) spatial and verbal working memory, because working memory depends upon directed attention; and (c) inhibitory control, which is important in EF tasks that demand inhibition of a prepotent response or inhibition of a previous rule and holding a new rule in memory. We used the same three-phase paradigm as previous research (first induce cognitive fatigue, then manipulate cognitive recovery, and finally assess the recovery) to compare the effectiveness of two 20-min walks on the recovery of young children's directed attention, inhibitory control, and spatial working memory. One walk was in a built urban area (hereafter "urban walk"); the other walk was in an urban park with many natural elements such as trees, grass, and gardens (hereafter "nature walk"). The following hypotheses were tested:

**Hypothesis 1 (H1):** Children would perform better on an attention task (continuous performance task [CPT]) following a nature walk than an urban walk.

**Hypothesis 2 (H2):** Children would perform better on an inhibitory control task (Go/No go task) following a nature walk than an urban walk.

**Hypothesis 3 (H3):** Children would perform better on a spatial working memory task following a nature walk than an urban walk.



**Hypothesis 4 (H4):** Seven- and 8-year-old children would perform better on a verbal working memory task (DSB) following a nature walk than an urban walk. Only 7- and 8-year-olds completed the DSB task due to the difficulty preschoolers have with completing the task.

These hypotheses are based on the ART proposition that natural environments can facilitate recovery of directed attention. Following the proposition that directed attention functions as a necessary resource for other EF (Kaplan, 1995), we expect that natural environments can facilitate recovery of other EF.

## Method

### *Participants*

Seventeen 4-year-olds ( $M = 4.53$  years,  $SD = 0.33$ ; 7 males, 10 females), sixteen 5-year-olds ( $M = 5.48$  years,  $SD = 0.34$ ; 7 males, 9 females), seventeen 7-year-olds ( $M = 7.4$  years,  $SD = 0.31$ ; 11 males, 6 females), and seventeen 8-year-olds ( $M = 8.50$  years,  $SD = 0.35$ ; 7 males, 10 females) participated in this study. Participants were recruited through local grade schools, preschools, newspaper ads, and flyers posted in the community. Children who had been diagnosed with attention deficits (according to parent report) were excluded from the study. A majority of the families were middle class and lived in an urban or suburban home with a yard. A majority was Anglo-American (69%), 7% were African American, and 24% did not report race/ethnicity. The legal guardians provided written consent, and the children provided verbal (4- to 5-year-olds) or written (7- to 8-year-olds) assent. Children were randomly assigned to complete either the nature walk or urban walk first.

### *Apparatus and Measurements*

*Attention fatiguing task.* Children first completed jigsaw puzzles to fatigue their attention. This manipulation was used to replicate Faber Taylor and Kuo's (2009) study in which they used jigsaw puzzles to fatigue the attention of children with attention deficits. The difficulty level of the puzzles varied depending on the age of the child such that the child was challenged by the puzzles, but was able to put the puzzles together without help.

*Computerized tasks.* Computerized tasks (Spatial Memory, Go/No go, and CPT) took place on a large 29 in  $\times$  42 in (74 cm  $\times$  107 cm) liquid crystal

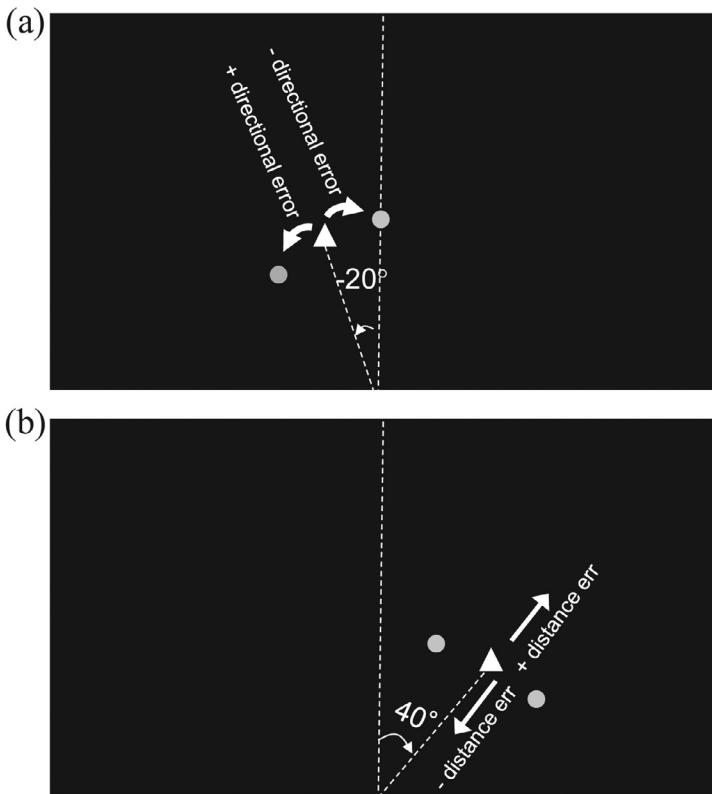
display (LCD) computer monitor (Sharp, Inc.) with a resolution of 1,024 × 760 pixels. The monitor was tilted 15° up from horizontal. The monitor had a touchscreen overlay (Smartboard) that reacted to the touch of a stylus. Children used the stylus during the Spatial Working Memory task and used the spacebar on the computer keyboard during the Go/No go and CPT.

*Spatial working memory task.* The spatial working memory task (Schutte, Keiser, & Beattie, 2015; Schutte & Spencer, 2002) measured the children's ability to remember the location of a target (i.e., spaceship, treasure, or bubble, 1 cm × 1 cm), while ignoring a distractor (i.e., yellow dot, 1 cm in diameter) that periodically appeared on the screen. The children were told that they would be playing a game that would involve "finding a lost spaceship," "finding the treasure chest," or "popping a bubble." Children played one game at the first session (spaceship, treasure hunt, or pop a bubble) and a different game at the second session. Which game was played at each session was counterbalanced across children. The games were alike except for their cover story (find a lost spaceship, find a treasure chest, or pop a bubble) and the shape of the target.

Prior to playing the game on the computer, the child and experimenter played a warm-up game on the floor using two flashcards: one with the distractor (yellow dot) and one with the target (spaceship, treasure chest, or bubble) After explaining the game, the experimenter placed the flashcards face down on the floor, and the child used a stylus to touch the target card. The child was required to complete two warm-up trials correctly before moving on to the actual game. Most children required only two to three warm-up trials.

Next, the child was seated in front of the monitor, and the task started with a demonstration trial (exactly the same as test trials) performed by the experimenter. The child completed two practice trials followed by the test trials. Each trial began when the computer said, "Let's look for a spaceship," "Let's find the treasure," or "Let's pop the bubble"; the target then appeared for 2,000 ms. Following a delay (see below), the computer said "go, go, go," and the child pointed to the target location with the stylus. After each trial, the target was re-illuminated for 4,000 ms. The child received verbal and visual feedback from the computer based on whether he or she found the target (was within 1.5 cm of the center of the target), was close to the target location (was within 4 cm of the center of the target), or did not find the target (see Schutte & Spencer, 2009).

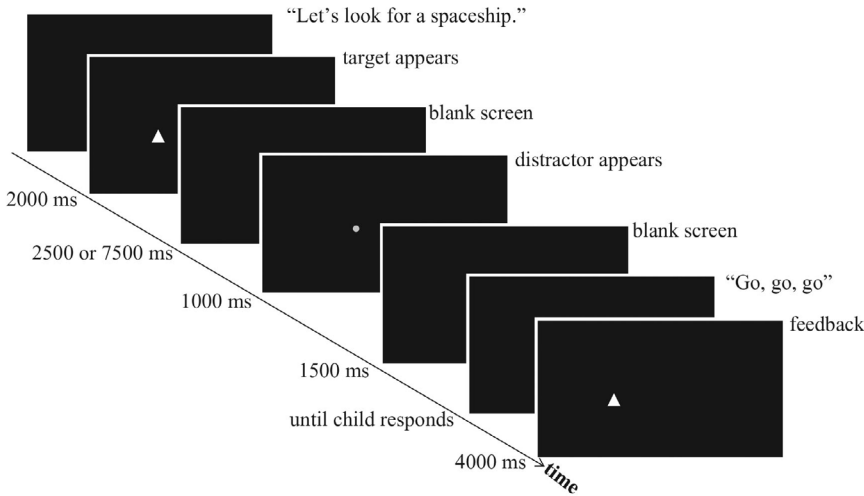
Children completed 24 test trials responding to one of two target locations (12 trials to each target). One target appeared 40° to the right of the midline of the monitor (40° target), and the other target appeared 20° to



**Figure 1.** Diagrams of the screen for the SWM task showing the target locations (white triangles) for the (a)  $-20^\circ$  target and the (b)  $40^\circ$  target. Gray dots mark the possible distractor locations for each target location. SWM = spatial working memory.

the left of midline ( $-20^\circ$  target; see Figure 1). The children responded after no delay (target remained illuminated until the child responded; 4 trials) or delays of 100 ms (4 trials), 5,000 ms (8 trials), or 10,000 ms (8 trials). During half of the 5 s and 10 s delays, a distractor target appeared at a location  $20^\circ$  from the target location. For the  $-20^\circ$  target, the distractor appeared at either  $-40^\circ$  or  $0^\circ$  (Figure 1a). For the  $40^\circ$  target, the distractor appeared either at  $60^\circ$  or  $20^\circ$  (Figure 1b). The distractor appeared 2,500 ms prior to the go signal and remained illuminated for 1,000 ms. See Figure 2 for a schematic of a complete trial sequence.

*Go/No go task.* Children completed a Go/No go task designed by Wiebe et al. (2011; Wiebe, Sheffield, & Espy, 2012). In each trial of the Go/No go task,



**Figure 2.** Schematic of one trial of the SWM task. The start of the trial is at the back, and time runs toward the front. SWM = spatial working memory.

either a fish or shark appeared on the monitor. Children pressed a spacebar to “catch a fish” when they saw a fish. The experimenter told children that the fish would “get away” if they were too slow to press the spacebar. The experimenter told the child not to press the spacebar when a shark came on the screen (i.e., “let the shark swim away”). The task began with a training procedure. First, children saw a screen containing pictures of the fish followed by four practice Go trials. Next, they saw a screen with pictures of the sharks that was followed by four practice No go trials. Following the training procedure, children completed 40 trials with 30 (75%) requiring Go responses (i.e., fish) and 10 (25%) requiring No go responses (i.e., sharks).

*CPT.* The CPT (Wiebe et al., 2012; Wiebe et al., 2011) was identical to the Go/No go task except that the number of Go trials was 14 (23%), and the number of No go trials was 46 (77%).

*DSB.* School-aged children completed a DSB task (Wechsler, 1955), in which they listened to the experimenter say a randomly generated sequence of numbers ranging from two to eight digits long (e.g., 1-2-3). Children repeated the sequence back to the experimenter in the reverse order (e.g., 3-2-1). If a child repeated two out of three trials correctly at a given span, the child was given another three trials that were one digit longer. If the child was unable

to complete two out of the three trials correctly, the game ended. Children were scored based on the longest span they were able to complete before they failed two trials.

## ***Procedure***

Children participated in two sessions that were generally scheduled a week apart. The procedure was the same for each session except consent forms were completed at the first session. The sessions took place in a laboratory on a university campus. The majority of participants (59 out of 67, 88%; 29 females, 30 males) came into the lab between late spring and summer, a time during which leaves were already on the trees. Seven participants came in during early fall (10.4%; 6 females, 1 male) when the leaves were still on the trees, but may have started to change colors. One male participant participated during late fall when some of the leaves may have already fallen off of the trees.

After completing consent forms, the child spent 10 min working on puzzles to fatigue his or her attention. Next, the child went on a 20-min urban or nature walk with the experimenter. The type of walk occurring in the first session was counterbalanced across participants. The experimenter instructed the child that he or she would be going on a walk where he or she was supposed to enjoy the surroundings, and because we wanted him or her to enjoy the surroundings, the child was asked not to talk during the walk. If the child began to talk or ask a question, the experimenter quickly answered the question and then reminded the child that it was important not to talk so he or she could enjoy his or her surroundings. Parents were invited to go along on the walk, and were instructed to avoid talking during the walk. It is estimated that only 20% of parents went on the walk. Out of those, a majority were parents of preschoolers. If a parent went on the first walk, the parent also went on the second walk to keep that factor the same for both sessions. Both walks started at the building containing the laboratory. After exiting the building, the experimenter and child either continued straight ahead and walked along busy streets in a downtown area (urban walk, see Figures 3a and 3c), or turned left and walked through a campus area that included many mature trees, green spaces, a "sculpture garden," flower gardens, and varied vegetation (nature walk, see Figure 3b and 3d). Both walks were similar in terms of terrain (flat) and cleanliness.

After the walk, the child came back into the laboratory and completed the spatial working memory task, Go/No go task, CPT, and the 7- and 8-year-olds completed the DSB task. The second session was the same as the first except that children completed the other type of walk (either urban or nature). Data collection sessions were rescheduled in the event of inclement weather.



**Figure 3.** Photographs from along the urban walk (a and c) and the nature walk (b and d).

***Method of Analysis***

We used signal detection theory to compute scores for the Go/No go and CPT data. Signal detection theory is a method used to model the decision-making process for someone who decides between two different classes of items, in this case, fish and sharks. A “hit” is when a signal is present and the individual correctly identifies the signal (i.e., a correct response, in our



Go/No go task when a fish appears, and the child correctly presses down the spacebar to “catch” the fish). A “false alarm” occurs when a signal is absent, and the person identifies the signal as being present (i.e., a commission error, in our Go/No go task when a shark appears, and the child presses the spacebar; Wiebe et al., 2011). The distribution of the sensitivity between a signal present and a signal absent response is measured by  $d'$  prime ( $d'$ ), which is the standardized difference between the means of the signal present and the signal absent distributions. If a person is more sensitive to a signal, the difference between the two distributions is larger in comparison with a person who is less sensitive to a signal. Thus,  $d'$  takes into consideration both performance and response bias. For example, a child who is 100% accurate on the Go trials (signal present), but also hits the button for all of the No go trials (signal absent) would receive a low  $d'$  score. Scores for  $d'$  were calculated for the Go/No go and CPT tasks using the  $z$  scores of the right-tail  $p$  values of the child's hit (H) and false alarm (FA) rates. The following formula was used to calculate each child's  $d'$  score:  $d' = z(\text{FA}) - z(\text{H})$  (Wiebe et al., 2011).

To examine whether exposure to nature had an impact on young children's performance on the Go/No go task, CPT, or DSB, we conducted ANOVA for each measure with age (preschoolers: 4-5 years, school-aged: 7-8 years) and gender (male, female) as between-participants variables; and type of walk (nature, urban) as a within-participants variable. The dependent variables for the Go/No go task and CPT were  $d'$  and mean reaction time on correct Go trials. The dependent variable for DSB was longest correct span.

To test the hypothesis that children would perform better on a spatial working memory (SWM) task following a nature walk, we analyzed children's constant directional and distance errors (see Figure 1; Schutte et al., 2015; Schutte & Spencer, 2002). Both types of errors show systematic biases that increase as delay increases (Schutte & Spencer, 2009). Thus, as the uncertainty of the memory increases, error becomes more biased rather than just increasing randomly (see Huttenlocher, Hedges, & Duncan, 1991). The memory responses of children within these age groups tend to be biased away from the vertical symmetry axis of the monitor (Schutte & Spencer, 2009), and in terms of distance errors, their responses “overshoot” or are above the target location following a delay (Schutte & Spencer, 2002). Directional errors toward midline were coded as negative, and directional errors away from midline were coded as positive (Figure 1a). Distance errors that were closer to the bottom center of the monitor than the target location were coded as negative (i.e., children undershot the target), and distance errors that were farther from the bottom center of the monitor were coded as positive (i.e., children overshoot the target; see Figure 1b). Inspection of the data revealed that there were a few trials where the participant



grabbed the bottom of the touchscreen before touching with the stylus at the remembered location. When this happened, the touchscreen erroneously recorded the touch at the bottom of the screen. These trials were removed from the analyses (50 trials, 1.6% of trials). Also, to remove any other erroneous touches or trials where the participant did not see the target, we removed trials with directional errors greater than  $30^\circ$ , which was approximately 3 times the standard deviation of  $11^\circ$  (78 trials, 2.4%).

Directional and distance errors on individual trials were examined using Proc Mixed in SAS. The Proc Mixed procedure is used to analyze mixed model and repeated measures by structured covariance models. This procedure allows you to model the means of the data as well as the variances and covariances (SAS Institute Inc., 2013). A compound symmetry covariance structure was utilized in which all variances and covariances were assumed to be equal. The main effects for the variables type of walk, delay (5 s and 10 s), as well as the interaction effect between the variables walk and distractor were examined. We only report main effects of or interactions with type of walk, because that is the variable of interest. Only 5 s and 10 s delays were used in this analysis, because these trials included a memory component. A preliminary analysis examining the no delay and 100 ms delay trial was conducted to examine whether the children in our sample understood and could complete the task without difficulty (e.g., their motor control abilities did not limit their accuracy). The model estimated error direction for the no delay trials was  $0.19^\circ$  ( $SE = 0.24$ ) and for the 100 ms delay trials was  $1.36^\circ$  ( $SE = 0.24$ ). Therefore, these children made small errors away from midline. The Least Square means distance error for no delay trials was  $-0.20$  cm ( $SE = 0.08$  cm) and for 100 ms delay trials was  $-0.31$  cm ( $SE = 0.08$  cm). In both instances, the children slightly undershot the center of the target, and touched the bottom of the target instead of the center (note that the target was  $1\text{ cm} \times 1\text{ cm}$ ). Importantly, both directional and distance errors at no delay and the 1 s delay were small, suggesting children were able to complete the task without difficulty. In addition, children slightly undershot the center of the target, which replicates the bias found by Schutte and Spencer (2002) for no delay trials.

## Results

### *Effects of Walk on Attention*

ANOVA of  $d'$  scores revealed a significant main effect of age,  $F(1, 63) = 14.62$ ,  $p < .001$ ,  $\eta_p^2 = .19$ . School-aged children had higher  $d'$  scores than the preschoolers (preschool:  $M = 5.54$ ,  $SD = 2.24$ ; school-aged:  $M = 7.18$ ,  $SD = 1.59$ ). There was also a significant main effect of gender,  $F(1, 63) = 6.13$ ,

$p = .016$ ,  $\eta_p^2 = .09$ . The girls had higher  $d'$  scores than the boys (females:  $M = 6.83$ ,  $SD = 1.78$ ; males:  $M = 5.87$ ,  $SD = 2.31$ ). There was no significant main effect of walk,  $F(1, 63) = 0.004$ ,  $p = .952$ ,  $\eta_p^2 = .000$ , but there was a significant Walk  $\times$  Age Group interaction,  $F(1, 63) = 5.62$ ,  $p = .021$ ,  $\eta_p^2 = .08$ . Follow-up two-tailed  $t$  tests for each age group did not reveal any significant effects of walk, preschoolers:  $t(32) = -1.50$ ,  $p = .144$ ; school-aged:  $t(33) = 1.63$ ,  $p = .113$ . A  $t$  test comparing age group for each walk type revealed a significant effect of age following the nature walk,  $t(65) = -4.03$ ,  $p < .001$ , but not the urban walk,  $t(65) = -1.48$ ,  $p = .143$ . Thus, the school-aged children had significantly higher  $d'$  scores than the preschoolers following the nature walk (preschoolers:  $M = 5.16$ ,  $SD = 2.72$ ; school-aged:  $M = 7.58$ ,  $SD = 2.18$ ), but not following the urban walk (preschoolers:  $M = 5.92$ ,  $SD = 2.64$ ; school-aged:  $M = 6.79$ ,  $SD = 2.08$ ).

The ANOVA of mean reaction time for correct trials revealed a significant main effect of walk,  $F(1, 62) = 4.54$ ,  $p = .037$ ,  $\eta_p^2 = .07$ . Children responded significantly faster following the nature walk,  $M = 665$  ms,  $SD = 81$  ms, than the urban walk,  $M = 687$  ms,  $SD = 85$  ms. There was also an age group main effect,  $F(1, 62) = 52.66$ ,  $p < .001$ ,  $\eta_p^2 = .46$ , but no Age Group  $\times$  Walk interaction,  $F(1, 64) = 0.103$ ,  $p = .750$ ,  $\eta_p^2 = .002$ . The school-aged children responded faster than the preschoolers (preschoolers:  $M = 731$  ms,  $SD = 61$  ms; school-aged:  $M = 628$  ms,  $SD = 51$  ms). Thus, children responded significantly faster following the nature walk than the urban walk, partially confirming H1.

### ***Effects of Walk on Inhibitory Control***

The ANOVA examining  $d'$  scores indicated no significant effects of gender, so gender was dropped from the ANOVA. The ANOVA revealed no significant main effect of walk,  $F(1, 63) = 0.59$ ,  $p = .445$ ,  $\eta_p^2 = .01$ , or any interactions with walk, all  $ps > .10$ . The only significant effect was age,  $F(1, 63) = 10.04$ ,  $p = .002$ ,  $\eta_p^2 = .14$ ; school-aged children had higher  $d'$  scores ( $M = 4.99$ ,  $SD = 2.37$ ) than preschoolers ( $M = 3.24$ ,  $SD = 2.0$ ).

The ANOVA of mean reaction time on correct trials revealed a main effect of age,  $F(1, 63) = 78.13$ ,  $p < .001$ ,  $\eta_p^2 = .55$ , but no significant main effect of walk,  $F(1, 63) = 1.67$ ,  $p = .201$ ,  $\eta_p^2 = .03$ , or any interactions with Walk, all  $ps > .10$ . School-aged children responded significantly faster ( $M = 593$  ms,  $SD = 49.4$  ms) than preschoolers ( $M = 721$  ms,  $SD = 65.2$  ms). H2 was not supported.

### ***Effects of Walk on Spatial Working Memory***

For the spatial working memory data, Restricted Maximum Likelihood (REML) was used in reporting model parameters and to assess the

significance of random effects; degrees of freedom were calculated using the Containment method. In the first analysis, constant directional error was the dependent variable and age group (preschoolers, school-aged); gender (male, female); type of walk (nature, urban); trial delay (5s, 10s); target location ( $-20^\circ$ ,  $40^\circ$ ); and distractor (no distractor, inner distractor, outer distractor) were independent variables. There was no significant main effect of walk,  $F(1, 64) = 1.77$ ,  $p = .19$ ,  $d = .12$ , or interactions with walk.

The same analysis procedure was used to examine constant distance error as the dependent variable. Positive errors indicate that children overshot the target, and negative errors indicate that children undershot the target. There was a significant main effect of walk  $F(1, 62) = 15.25$ ,  $p < .001$ ,  $d = .27$ . Children were accurate following the nature walk ( $M = 0.01$  cm) and overshot the target after the urban walk ( $M = 0.42$  cm). There was also a significant Gender  $\times$  Walk interaction  $F(1, 63) = 6.55$ ,  $p = .013$ , and a significant Age Group  $\times$  Walk interaction,  $F(1, 63) = 4.08$ ,  $p = .048$ . Boys were less biased after the nature walk ( $M = -0.04$  cm,  $SE = 0.19$  cm) in comparison with the urban walk ( $M = 0.63$  cm,  $SE = 0.19$  cm). Girls showed little bias after both the urban walk ( $M = 0.05$  cm,  $SE = 0.18$  cm) and the nature walk ( $M = 0.21$  cm,  $SE = 0.18$  cm). Examination of simple effects revealed a significant difference between the nature and urban walk for boys,  $t(63) = -4.52$ ,  $p < .001$ ,  $d = .64$ , but not for girls,  $t(63) = -1.08$ ,  $p = .282$ ,  $d = .15$ . In addition, the preschoolers touched the bottom of the target following the nature walk ( $M = -0.24$  cm,  $SE = 0.19$  cm), but overshot it following the urban walk ( $M = 0.38$  cm,  $SE = 0.19$  cm). In contrast, the school-aged children overshot the target following both walks (nature walk:  $M = 0.25$  cm,  $SE = 0.18$  cm; urban walk:  $M = 0.46$  cm,  $SE = 0.18$  cm). Follow-up tests revealed a significant difference between the nature and urban walk for the preschoolers,  $t(63) = -4.12$ ,  $p < .001$ ,  $d = .57$ , but not the school-aged children,  $t(62) = -1.47$ ,  $p = .15$ ,  $d = .20$ . Thus, H3 was partially supported.

### ***Effects of Walk on a Measure Combining Attention and Verbal Working Memory***

Mean backwards digit span following the nature walk and following the urban walk were both about 3 digits (nature walk:  $M = 3.09$ ,  $SD = 0.75$ ; urban walk:  $M = 3.03$ ,  $SD = 0.80$ ). H4 was tested in a two-tailed  $t$  test. There was not a significant difference in performance following the two types of walks,  $t(33) = -0.47$ ,  $p = .644$ ,  $d = .08$ . Thus, H4 was not confirmed.

**Table 1.** Summary of Effects.

	Walk main effect	Walk × Age Group	Walk × Gender	Walk × Age Group × Gender
Attention (CPT)				
$d'$	<i>ns</i>	*	<i>ns</i>	<i>ns</i>
Reaction time	*	<i>ns</i>	<i>ns</i>	<i>ns</i>
Inhibitory control (Go/No go)				
$d'$	<i>ns</i>	<i>ns</i>	<i>ns</i>	<i>ns</i>
Reaction time	<i>ns</i>	<i>ns</i>	<i>ns</i>	<i>ns</i>
Spatial working memory				
Directional error	<i>ns</i>	<i>ns</i>	<i>ns</i>	<i>ns</i>
Distance error	**	*	*	<i>ns</i>
Verbal working memory (DSB)	<i>ns</i>			

CPT = continuous performance task; DSB = Digit Span Backwards.

\*  $p < .05$ ; \*\*  $p < .001$

## Discussion

This research examined the effectiveness of a 20-min walk in a natural environment in promoting cognitive recovery of young children. We hypothesized that children would perform better on measures of attentional control, inhibitory control, and working memory after a nature walk than after an urban walk. Table 1 summarizes the significant and non-significant results. We will consider each of the hypotheses.

The first hypothesis, that attentional control would be better following a nature walk than an urban walk, was supported by the reaction time results (see Table 1). This finding is consistent with Berto (2005), who reported significant improvements in attention of young adults after viewing restorative (nature) photos but not after viewing non-restorative (non-nature) photos. In the current study, reaction times on the attention task were faster following the nature walk, but children's ability to discriminate the fish from the sharks, as measured by  $d'$ , did not change. The lack of effect for the  $d'$  measure is most likely due to a ceiling effect. Across both walks, the majority of children made no mistakes, or only one or two. The difference in speed of response suggests more efficient and/or less "costly" processing after the nature walk compared with the urban walk, consistent with ART.

The second hypothesis, that children would perform better on an inhibitory control task (Go/No go) following a nature than an urban walk,

was not supported (see Table 1). The fact that there was a positive effect of the nature walk on the attention task, which was completed after the inhibitory control task, suggests that this was not due to the influence of nature “wearing off” before children completed the inhibitory control task. Rather, this result suggests that exposure to nature may not have the same influence on inhibitory control as on attention in children. This result contrasts with the result of Faber Taylor et al. (2001) who found that girls with greener views from their home performed better on tasks involving inhibitory control. There are several differences between the studies that may account for this difference in results. First, the tasks were different. The Go/No go task may not have been as sensitive as the battery of tasks used by Faber Taylor et al. (2001). Second, it is possible that the short exposure to nature in the walk did not influence inhibitory control in the same way as continual exposure to green space around the home. Higher levels of exposure to nature over the course of development may be necessary to influence inhibitory control. Before this can be stated conclusively, however, future research should replicate the influence of nature on inhibitory control in children using different inhibitory control tasks.

The third hypothesis, that children would perform better on a spatial working memory task following a nature than an urban walk, was partially supported for preschoolers who were more likely to “overshoot” the target following the urban walk and “undershoot” it following the nature walk. Schutte and Spencer (2002) found that children were likely to undershoot the target on 1 s delay trials (they did not include no delay trials) and overshoot the target at 5 s and 10 s delays. We replicated their findings only in the urban walk condition, but in the nature walk condition, memory remained stable and responses following 5 s and 10 s delays were equivalent to responses at no delay and 1 s delay. Thus, in terms of distance errors, the performance of the preschoolers following the nature walk was better than following the urban walk. Performance of the school-aged children was in the same direction (smaller distance errors following the nature walk), but not significant. The reason for this age difference is not known, and this result should be replicated to determine if a different manipulation may result in a significant difference for school-aged children. For example, it is possible that the school-aged children’s attention was not fatigued enough by the puzzles to detect a significant difference in performance on the first task completed after the walks. Even though the puzzles the school-aged children completed were more difficult than the puzzles completed by the preschoolers, the amount of time they spent doing the puzzles was not any longer than the time spent by the preschoolers. School-aged children may require a longer amount of time than do preschoolers to fatigue their directed attention enough for there to be a significant influence of walk on the first task they complete.

Performance on the spatial working memory task following the nature and urban walks also differed for boys. Following the nature walk, boys' distance errors were not biased, that is, mean error was near 0; however, following the urban walk, boys overshot the target (Schutte & Spencer, 2002), indicating their memory of location drifted upward during the delay. Thus, in terms of distance errors, boys' performance following the nature walk was better than following the urban walk, that is, memory remained stable during the delay. Girls in this study did not show bias in distance errors following either walk. Previous research has found that girls perform better on tests of attention than do boys (Naglieri & Rojahn, 2001). Girls are also less likely to display symptoms of ADHD than are boys, even among children not diagnosed with ADHD (Cuffe, Moore, & McKeown, 2005; Lavigne, LeBailly, Hopkins, Gouze, & Binns, 2009). The spatial working memory task was the first task participants completed, so it is possible that following the urban walk, the girls were able to maintain their directed attention during the first task whereas the boys were not.

We did not find an effect of walk in the analysis of constant directional error. This lack of effect may have been due to the presence of a large amount of individual variability in both the direction of and magnitude of directional error across this age range (Schutte & Spencer, 2009) resulting in not enough power to detect an effect of walk. Studies have found that between 3 and 6 years of age, spatial working memory develops rapidly, which results in a change in the direction of constant directional error in tasks such as the one used here. Specifically, the memory responses of 3-year-olds are biased toward the center of the space, whereas the responses of 6-year-olds are biased away from the center of the space (e.g., Schutte & Spencer, 2009). As a result, children between 3 and 6 years of age are highly variable, sometimes making errors toward the center of the space and sometimes making errors away from the center of the space (Schutte & Spencer, 2009). Therefore, it is perhaps not surprising that walk type had an effect on constant distance error, which only decreases in magnitude across this age range, but not on constant directional error.

The fourth hypothesis, that 7- and 8-year-olds would perform better on a task involving both attention and working memory (DSB) following a nature than an urban walk, was not supported. This result is inconsistent with results reported by Berman et al. (2008) in samples of adults and with results reported by Faber Taylor and Kuo (2009) in a sample of school-aged children with ADHD. There are several possible explanations for this difference.

First, it is possible that the natural environment did not have a restorative effect on this dimension of attention and executive function for

children in this age range. However, this explanation would be inconsistent with the faster reaction time on the CPT, a measure of directed attention, after the nature than the urban walk.

Second, the DSB was the last assessment completed, occurring approximately 25 min after the end of the walk. If there were a restorative effect of the nature walk, it may have diminished by the time participants completed the DSB. This study also required two correct responses (out of three) at each span, which is a more stringent requirement than the one correct response (out of two) required by Faber Taylor and Kuo (2009). Similarly, the previous three measures (spatial working memory, Go/No go, and CPT) may have depleted directed attention. In the Faber Taylor and Kuo (2009) study, children completed the DSB first.

Third, the null finding for DSB may be due to the fact that the DSB involves multiple cognitive functions. Carlson (2005) found that tasks involving a combination of inhibition and working memory were the most difficult at every age. Faber Taylor and Kuo may have found an effect of walk type on DSB, because they included a larger age range (7-12 years) and had a higher mean age overall ( $M = 9.23$  years) than was true here.

In summary, the results provide some support for the hypotheses generated by ART. Children performed better on the measure of attentional control, and boys and preschoolers performed better on the measure of spatial working memory following the nature walk than following the urban walk. However, children did not perform better on a measure of inhibitory control or a measure combining attention and verbal working memory (DSB) following the nature walk compared with the urban walk. These results suggest that despite their less well-developed attentional system (e.g., Fisher et al., 2013; Ruff et al., 1998), even young children can benefit from time in nature.

### ***Limitations, Contributions, and Future Directions***

Limitations of this study point to future directions. First, the design does not allow us to determine why walk type did not influence all measures. For example, one possibility is that completing puzzles did not sufficiently fatigue children's directed attention. It is possible that puzzles were sufficiently fatiguing for participants in the Faber Taylor and Kuo (2009) study because they were diagnosed with attention deficits. Children without attention deficits may need a more challenging task or a longer period of time to fatigue their attention to the same level as those with attention deficits. The effects on the directed-attention task and spatial working memory task suggest that the puzzles at least somewhat fatigued attention, but utilizing different tasks to induce attentional fatigue in children should be examined in future research. Another possibility is that children did not



improve on some measures because the nature walk was not restorative enough. The walk was through a green, park-like space on a university campus. Although the campus has a large area with trees and vegetation, built areas were always somewhat in view. This limitation to the nature walk is also a strength, however, because the results show that even a limited green space similar to what can be found in urban parks can have some positive effects.

A second limitation of this study is that we did not have a baseline measure of attention following the puzzle task. Checking for attentional fatigue in children can be difficult, because including a pretest could result in practice effects on the post-test. Also, completing the behavioral measures only once allowed for shorter sessions, which is key when working with preschoolers. The fact that children performed better on some measures following the nature walk suggests that the type of walk had an effect on their cognitive functioning; however, these data do not speak to whether this was due to restoration of attention following the nature walk or due to attention being depleted more during the urban walk than the nature walk. Similarly, we also cannot determine whether the improvement was due to attention recovery, as proposed by ART, or due to a reduction in stress, as proposed by psychophysiological SRT (Ulrich et al., 1991). In future research with children, it will be important to combine measures of cognitive functioning, affect, and physiological responses to more precisely test restorative processes proposed by alternative theories.

A third limitation is the sample. The generalizability is somewhat limited due to the homogeneity of the sample. The majority of the sample of children was from middle-class homes and was Anglo-American. In addition, due to the nature of laboratory research, they all had legal guardians who were willing to bring them to the laboratory, which somewhat limits the sample. In addition, some of the null effects may have been due to having a sample of only 67. This sample size is larger or equal to many other experimental studies of the effects of nature (e.g., Berman et al., 2008; Faber Taylor & Kuo, 2009; van Den Berg & van den Berg, 2011); however, due to children's performance being more variable than that of adults, a larger sample may be needed for sufficient power to detect significant effects.

A fourth limitation was that DSB was always the last task, because, given the number of tasks, our sample size was not sufficient to counterbalance and analyze the order of tasks. Results of previous research (Berman et al., 2008; Faber Taylor & Kuo, 2009) may be replicated if the DSB is administered first in future research.

The limitations discussed here also provide suggestions for future research. In addition to these suggestions, there are several other issues future research should examine. For instance, research is needed to address

the question of how long the putative restorative effects of a nature walk will last, or whether the length of time it lasts varies over development. Following the nature walk, boys showed better performance in the spatial working memory task, the first task administered after the walk, and both boys and girls performed better on the measure of attention, the third task. Seven- and 8-year-olds' lack of improvement in the DSB, the fourth task, may have been due to the restorative effects "wearing off." The previous three tasks may have exhausted their directed attention—even after being restored by the nature walk. Future research is needed to examine how long the restorative effects of nature last and whether the effects change over development as this question has practical importance for educational settings.

Future work is also needed to examine the mechanisms through which natural environments are restorative. Neuroimaging methods will provide the opportunity to examine the underlying mechanisms. Before undertaking this work, however, researchers need an understanding of how far-reaching this effect is, both in terms of the cognitive abilities that are influenced and which populations are affected. Although a fair amount of research with adults has provided insight regarding these effects, equivalent work examining these effects in typically developing children is limited. The current study is a first step in characterizing the influence of time in nature across two different age groups of typically developing children.

Another fruitful direction for future research would be to examine how the size, or scale, of the outdoor space influences children's cognition. For example, preschools and early childhood centers tend to have outdoor spaces that are a smaller scale than that of grade schools. The scale of the space may influence how restorative the space is, and this may vary with age. Similarly, the number of "green" elements such as trees, shrubs, and grass can be examined using objective measures such as those used by Faber Taylor et al. (2002) and Wells (2000). Considering that significant benefits have been observed through viewing pictures or video of nature as well as through window views (e.g., Berman et al., 2008; Berto, 2005; Kuo, 2001; Tennessen & Cimprich, 1995), humans may be particularly sensitive to stimuli of natural environments, but determining minimum thresholds will be important for informing applications in educational and other settings.

In conclusion, executive functioning undergoes rapid development in early childhood and includes critical competencies for success in academic contexts and everyday life. Thus, determining what types of practices and environments can have a positive influence on executive function in early childhood is critical, because environments may have different influences at different points in development. Therefore, these findings along with those from other studies have important implications for educators and policymakers as they make decisions about green space in child playgrounds,

amount of time for recess, and even the planting of trees and the provision of green space in urban neighborhoods. The lack of exposure of children to natural environments may have many consequences for their health and well-being, especially if they suffer from developmental disorders such as ADHD.

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