Urban Forestry & Urban Greening 86 (2023) 128005

Contents lists available at ScienceDirect

Urban Forestry & Urban Greening

journal homepage: www.elsevier.com/locate/ufug

In situ psycho-cognitive assessments support self-determined urban green exercise time

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ARTICLE INFO

Handling Editor: Dr Cecil Konijnendijk van den Bosch

Keywords:
Urban greenspace
Green exercise
Cognitive response
Mood
Nature affinity
Ecological momentary assessment

ABSTRACT

Prescribed nature walks frequently yield improvements to mood and cognition as observed in experimental studies. Research that uses real life settings such as self-determined time exercising outdoors for restorative health benefits may more accurately elicit effects than time-specified study protocols. This study examined in situ psycho-cognitive outcomes of routine walks in urban greenspace to test the concept that self-set exposure duration and not context alone is related to magnitude of psycho-cognitive benefit. Pre-post measurements taken on a diverse participant pool of individuals walking in urban parks and recruited on random days over a two-week period found significant associations between outdoor activity duration and cognitive and mood improvements. Greater outdoor walking duration linearly predicted stronger processing speeds but non-linearly in tests of other cognitive domains. Results of fixed effects model for mean mood change following green exercise show outdoor walking influenced mood change at highest levels of significance, even after accounting for individual level variability in duration. Mood improved for all durations of outdoor walking under a random effects model with high significance. Untethering fixed intervals of outdoor exercise from formal study design revealed briefer but more frequent nature engagement aligned with nature affinity. The influence of unmeasured factors, e.g., nature affinity or restorative conditioning, for prescriptive durations of urban green exercise merits further investigation toward designing wellbeing interventions directed at specific urban populations.

1. Introduction

Perceptual overload and emotional disquiet dispose modern society to a continual state of distraction and confusion (Lavie, 2005). Sustained attentional capacity is crucial in executing cognitive tasks (Diamond, 2013). Yet the ability to maintain attention against competing visual and aural stimuli throughout the day equally challenges students, transport drivers, office and medical workers. Erosion of attentional capacities occurs against a background of contemporary nature alienation (Cox et al., 2017; Turner et al., 2004; Ventriglio et al., 2021). Reduced time spent outdoors ironically diminishes the strong potential for routine nature contact to offset cognitive and emotional fatigue through processes favoring attention restoration and stress reduction (Berto, 2005; Corazon et al., 2019; Kaplan and Kaplan, 1989; Kaplan and Berman, 2010; Kaplan, 1995; Kondo et al., 2018). Artificial leisure directly competes with time in nature, while a shift from outdoors to indoors suppresses the cultivation of latent nature affinity, a trait inclining individuals to seek out natured environments, often for restorative ends.

Nature affinity predisposes individuals to seek out nature for restoration (Mayer et al., 2009; Mayer et al., 2009; Sheffield et al., 2022). Research has assessed the value of nature connectedness in spurring the use of local urban parks, not broader experiences in diverse natured settings, due to the narrowing experiences within nature many of today's urban residents confront (Scopelliti et al., 2016; Lin et al., 2014). Global urbanization trends will further elevate the importance of greenspace within cities as a locus for wellbeing. Urban parks may

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https://doi.org/10.1016/j.ufug.2023.128005
Received 22 December 2022; Received in revised form 12 June 2023; Accepted 13 June 2023
Available online 17 June 2023

therefore offer city residents opportunities for cognitive and emotional reset, given the robust evidence sustaining that natural outdoor environments positively impact neurocognition and psycho-physiological endpoints (Andersen et al., 2021; Holland et al., 2021; Jimenez et al., 2021; Kondo et al., 2015; Kondo et al., 2018; Gidlow et al., 2016; Labib et al., 2020).

A cornerstone theory of nature exposure is Attention Restoration Theory (ART) whereby attentional capacity resets in nature by being redirected toward less cognitively demanding settings (Berto, 2005; Kaplan and Kaplan, 1989; Kaplan and Berman, 2010; Hartig and Evans, 1993; Hartig et al., 2003; Ohly et al., 2016; Stevenson et al., 2018; Shin et al., 2011). Evidence for the attention restoration benefits of urban nature walks comes primarily from experimental field studies circumscribing participants' nature contact. Most randomized studies have assessed changes in various cognition domains by dichotomously comparing urban walks through built versus natured environments (Bailey et al., 2018; Beil and Hanes, 2013; Bratman et al., 2015; Jones et al., 2021; Kondo et al., 2020; Triguero-Mas et al., 2017; Tyrväinen et al., 2014) or physical activity performed indoors versus in parks (Lahart et al., 2019; Li et al., 2022; Mnich et al., 2019). Walking in urban green outperforms urban gray almost without exception for restoring attention and dampening stressors such as traffic, crowds and noise on the autonomic nervous system (Krabbendam et al., 2021; Browning et al., 2022), though study results may indicate some somatic rejection of non-natured control environments (Hartig et al., 2003), and interactions and temporality remain open questions.

The literature also affirms that green exercise positively effects emotional markers including overall mood (Kondo et al., 2018; Barton et al., 2016; Lee and Maheswaran, 2011; Tsunetsugu et al., 2013), despite occasional exceptions (Gidlow et al., 2016). Exercise performed in urban nature is shown to improve mood irrespective of cognitive change (Schertz and Berman, 2019; Stenfors et al., 2019). Meta-analyses of mood-related data support that mood improves following walks in urban nature (Li et al., 2022; Browning et al., 2020; McMahan and Estes, 2015; van Heezik et al., 2021). A fixed 30-minute nature internal also governs the design of many of these two-by-two studies which emphasize environmental context as the exposure variable, although "optimal dosage for maximum benefits" remains undefined (Barton et al., 2012).

Associations between time in urban greenspace and observed effect in fact fluctuate widely in the literature. Barton and Pretty (2010) found the greatest increase to mood occurred after only five minutes of green exercise, suggesting psychological measures are highly sensitive to natural environments, a result also confirmed in testing five-minutes rest in nature on mood (Neill et al., 2019). One scoping review concluded that a mere 10 min in varied natured settings elicited significant and positive psychological improvements in mental well-being (Meredith et al., 2020), while 20 min sufficed to reduce ADHD symptoms among children (Faber Taylor and Kuo, 2009). Elsewhere 50 min exposure windows have been employed to test cognitive improvements in nature (Hartig et al., 2003; Berman et al., 2008), and even 90 min outdoors have been assigned to measure changes in neurological activity (Bratman et al., 2015). Nineteenth-century landscape architect and public health practitioner Frederick Law Olmsted recommended city dwellers spend two hours per week in urban parks (Olmsted, 1882), an amount identical to the 120-minute target for weekly nature time found 150 years later (White et al., 2019).

Still, assessments of urban context and duration latitude in nature tend to exclude subjective dimensions of urban green exercise such as self-determined time walking outdoors. The relationship between urban green exercise time and psycho-cognitive effect under prescribed conditions might in fact differ under more realistic conditions of local, routine urban nature walks. Pasanen et al. (2018) advocate that a realistic nature setting rather than experimental conditions is preferable for confirming external validity of study findings. Hunter et al. (2019) emphasize the effect of behavior adaptability on mental health "within the context of daily life" among healthy adults by examining self-directed nature exposure under which participants selected their own duration and green exercise conditions. A small number of studies have allowed participants to select their own duration and conditions in nature to study the effect on mood of repeated walks in self-chosen nature (Jones et al., 2021; Kerr and Vlaswinkel, 1993), or have included cognitive tasks completion during self-directed trail walking (Pasanen et al., 2018; Korpela et al., 2008).

Self-determined time targets in urban nature moreover may embed other unmeasured factors typically unaccounted for in dose-response relationships. For example, Flowers et al. (2016) theorize that a stronger sense of nature connectedness summons more frequent outdoor exercise, which in turn induces positive changes in affect. Expectancy effects by which individuals proactively seek out urban nature in settings found to be reliably therapeutic may potentially contribute to the psychological benefits of green exercise (Flowers et al., 2018). The motivational properties of physical activity may account for how contrasting environments influence mood and how natural environments specifically induce cognitive improvements (Ekkekakis, 2003). Positive motivation has been previously found to enhance physical activity performance (Pasanen et al., 2018) as well as cognitive control and executive functioning (Sachs et al., 2017). Conditioned restoration theory has empirical bases to support that positive affective responses occur with associative retrieval of previously enjoyed natured environments (Egner et al., 2020). Other factors unmeasured at the individual level, e.g, pro-environmentalism (van Heezik et al., 2021), mindfulness (Choe et al., 2020; Lymeus et al., 2017), or socialization (Meredith et al., 2020), may also subconsciously enhance the positive effects of green exercise such that "urban nature self-dosing" bypasses prescriptive spans of engagement (Kanning and Schlicht, 2010).

Promoting urban greenspace as an agent of emotional and cognitive restoration perhaps obliges researchers to study individuals engaging in routine outdoor exercise under authentic local conditions. Sullivan and Li (2021) affirm that habitual contact with natural settings such as urban green vitally impacts attentional functioning. In situ response gathering allows real-time assessment of "stimuli-emotional response" that reflects everyday realized nature engagement and not hypothesized use (Kondo et al., 2020) in actual contexts of occurrence (Davis and Gatersleben, 2013). Several researchers have offered evidence supporting this position, setting study control conditions aside, especially as regards changes in mood (Neill et al., 2019; Passmore and Holder, 2017; Passmore and Howell, 2014). However, experimental studies using a between- or within-subjects design are infrequent due to the difficulty of randomly sampling populations. Finally, assessing the participant experience within a realistic urban nature setting might add to the validity of physiological responses under actual conditions where green exercise is routinely performed, since experimental protocols may produce different effects than those observed in more organic conditions.

This study design thus shifts away from contrasted urban walking contexts to measure cognitive and mood changes within the realistic setting of self-assigned green exercise duration among routine walkers. It complements the existing, mainly dichotomous research designs on the effects of outdoor walks in considering the role of participant- rather than investigator-established duration outdoors as an independent predictor of effect. Participant-determined time outdoors may contribute to within-subject differences in this study under similar outdoor exercise conditions, befitting Jones et al.'s assertion that a "30-minute nature walk may be insufficient to induce [predicted] effects" (Jones et al., 2021).

We hypothesize that individuals' routine patterns of urban green exercise will align with self-expressed nature affinity in ways that fulfill innately perceived physical and psychological needs and that this alignment will be reflected in quantifiable magnitude of effect. We pose three research questions (RQ) to explore this. RQ1: Does duration of urban green exercise influence magnitude of psycho-cognitive benefit? RQ2: Does nature affinity predict changes in affect within the context of local, routine urban nature exposure? RQ3: Is mood change sensitive to urban green exercise, and does expectancy condition this association?

Urban nature exposure is limited here to manicured parks, greenways, and campuses, excluding wilder natured settings within and beyond cities. Duration of urban park walks is explored as a treatment effect and intrinsic affinity toward nature considered as a moderator of main effect. We look to detect clear response signals between and within individuals in a mixed effects model investigating everyday green exercise. Asking a diverse population to participate in a study that applies novel protocols will also inform on participant compliance and reliability of on-site data collection using an interactive survey platform customized for this exploratory study.

2. Results

Eighty-two participants returned data at varying compliance levels for different aspects of the study protocol exploring the duration of green exercise as a predictor of psycho-cognitive outcome. 95.6% contributed covariable data, consisting of SF12, other health, and socio-demographic information; 80.5% completed pre-post mood questionnaires, and 72.0% the addition (ADD) and Stroop measures. ADD and Stroop scores were recorded for 59 participants, producing 4674 total cognitive data points.

2.1. Main findings

Table 1 shows participants' mean scores and standard deviations for mood and timing of cognitive responses before and after outdoor exercise for categorized self-determined time in nature, with all descriptive statistics reaching high significance.

2.2. Cognitive outcomes

Our first research question investigated if duration of urban green exercise influences magnitude of cognitive benefit. Outdoor walking duration in urban parks or campuses modeled continuously and categorically and participant ID served as our main model predictors for measuring within-person magnitude of change. Decreases in Stroop response times improved in the range of 6.0–19.7% across duration intervals and by 13.5–24.1% for the ADD tests. Results showed a significant main effect of walking duration in urban nature on directed attention which strengthened for Stroop response time and Stroop throughput. Magnitude of response appears strongest for outdoor walkers of between 30 and 60 min for Stroop Effect and ADD response timing and throughput. Table 2 presents regression estimates for unadjusted and adjusted effect models for cognitive changes.

Table 1
Descriptive statistics for means ± standard deviations of main cognitive scoring effects before and after intervention.

Outcome (mean ± SD)	Before interaction	After interaction	Delta
Stroop timing[a] (N = 59)	2409.78 ± 1454.57	1735.93 ± 782.25	-647.25 ± 1304.20
< 30 min (N = 17)	2431.46 ± 1081.11	1860.62 ± 421.53	-621.26 ± 1149.91
≥ 30 to ≤ 60 min (N = 27)	2611.51 ± 1784.75	1791.73 ± 936.24	-718.43 ± 1528.97
> 60 min (N = 15)	1767.46 ± 428.62	1332.65 ± 329.66	-424.98 ± 319.51
ADD timing[a] (N = 60)	10550.34 ± 4866.03	8492.08 ± 4049.75	-2133.76 ± 3184.46
< 30 min (N = 17)	11394.39 ± 4487.52	9739.87 ± 3922.79	-1997.95 ± 3321.22
≥ 30 to ≤ 60 min (N = 27)	10886.64 ± 5505.52	8486.89 ± 4440.44	-2385.43 ± 3481.81
> 60 min (N = 16)	7511.64 ± 1780.80	6709.29 ± 1493.55	-1330.82 ± 1342.97

[a] Response in milliseconds

Table 2
Results from base and adjusted models associated with green exercise intervention.

Outcome	*Model 1*[a]	*Model 1 p-value*	*Model 2*[b]	*Model 2 p-value*
Stroop Test				
Timing of response[1]	2119.86 (1979.83, 2266.17)	< 0.001	2083.33 (1971.97, 2192.84)	< 0.001
< 30 min	-134.93 (242.98, −26.88)	< 0.001	-131.95 (−236.81, −25.35)	< 0.001
≥ 30 to ≤ 60 min	-285.12 (−358.75, −211.54)	0.015	-295.44 (−371.38, −218.98)	0.016
> 60 min	-322.71 (−424.63, −211.59)	< 0.001	-275.42 (−384.69, −158.83)	< 0.001
Stroop Effect[2]	1423.32 (1320.16, 1526.90)	< 0.001	1407.14 (1320.76, 1491.31)	< 0.001
< 30 min	-108.55 (−275.81, 58.88)	0.21	-95.89 (−251.74, 65.61)	0.26
≥ 30 to ≤ 60 min	-212.74 (−329.43, −97.00)	< 0.001	-216.04 (−338.35, −97.58)	0.001
> 60 min	-155.31 (−312.26, 3.16)	0.06	-102.01 (−264.22, 84.36)	0.26
Throughput[3]	35.73 (32.99, 38.44)	< 0.001	34.75 (31.98, 37.55)	< 0.001
< 30 min	2.24 (−2.39, 6.72)	0.36	2.25 (−2.25, 6.48)	0.33
≥ 30 to ≤ 60 min	5.16 (2.01, 8.33)	0.002	5.70 (2.58, 9.31)	0.001
> 60 min	5.86 (1.58, 10.13)	0.01	6.86 (−1.68, 11.23)	0.007
Addition Test				
Timing[1]	8067.07 (7167.70, 8967.73)	< 0.001	8360.92 (7263.21, 9441.46)	< 0.001
< 30 min	-1321.45 (−2331.59, −306.24)	0.01	-1308.09 (−2280.99, −222.03)	0.013
≥ 30 to ≤ 60 min	-1983.42 (−2675.65, −1290.40)	< 0.001	-2183.74 (−2919.12, −1426.11)	< 0.001
> 60 min	- 1356.73 (−2283.97, −432.66)	0.004	-959.53 (−2038.25, 68.48)	< 0.001
Throughput[3]	7.42 (6.62, 8.22)	< 0.001	7.36 (6.33, 8.41)	< 0.001
< 30 min	1.20 (−0.36, 2.69)	0.12	1.14 (−0.59, 2.66)	0.18
≥ 30 to ≤ 60 min	1.76 (0.71, 2.81)	0.002	1.82 (−0.65, 3.05)	0.005
> 60 min	1.14 (−0.25, 2.53)	0.12	0.80 (−0.91, 2.42)	0.37

[a] Base model 1 effect measure: outcome ∼ duration + (1|PID)
[b] Model 2 adjusted for duration, hypertension, categorical age, smoking, current urbanicity and (1|PID)
[1] ms = milliseconds
[2] difference of incongruent - congruent trials
[3] rpm = correct response per minute

Model 1 associates main outcomes with duration of green exercise and trial number to account for learning effects which may have accelerated post-intervention response timing. Response time fell as an effect of continuous duration of green exercise ($\beta = -124.37$ ms (CI: $-148.75, -99.66$), $p < 0.001$). Categorical outdoor walking times of < 30, ≥ 30 to ≤ 60, and > 60 min increments were all associated with significant reductions in Stroop response time (Model 1). Stroop effect reflecting the interference of incongruent cognitive information ($\beta = -77.49$ (CI: $-116.94, -37.79$), $p < 0.001$) as well as Stroop throughput ($\beta = 2.23$ (CI: 1.16, 3.30), $p < 0.001$) also improved significantly when outdoor walking duration was modeled continuously, but only for categorical durations of 30–60 min for Stroop Effect and over 30 min for

Stroop throughput, despite absolute improvements for all individuals.

A significant main effect of urban walking on improved ADD response timing was observed for all individuals under continuous duration modeling (β = −716.63 ms (CI: −947.13, −486.13), $p < 0.001$) as well as categorical green exercise duration. Only duration between 30 and 60 min associated significantly with improvements in ADD throughput, even though continuous duration showed a modest but highly significant link to correct ADD responses (β = 0.62 (CI: 0.25, 0.98), $p < 0.001$).

2.3. Covariable analyses

The adjusted models (Table 3, Model 2) showed little change in measures of response speed for either the Stroop or ADD tests as an effect of categorized green exercise duration. As with the unadjusted model, the association between categorical duration in nature and Stroop Effect under adjustment showed significance among only ≥ 30 to ≤ 60 min green exercisers (β = −216.04 (−338.35, −97.58), $p < 0.001$) and among those walking outdoors over 30 min for both Stroop and ADD throughput measures. Bivariate relationships between the base-model predictor variables and ten covariates (categorical age, gender, childhood urbanicity, current urbanicity, nature affinity, BMI, smoking (current or former), doctor-diagnosed hypertension, Type 2 diabetes, and a composite short-form SF-12 physical and emotional health score) were test for significance using p-values. The four covariables reaching α = 0.05 level of significance—hypertension, current urbanicity, smoking, and categorical age, a highly significant covariable in post-hoc analysis—were then added to duration and participant ID in an adjusted model. Covariable adjustment appeared to significantly attenuate response speed and throughput but not Stroop Effect for individuals aged 18–34 and current smokers. Fig. 1a-b show speed of Stroop and addition response times peak among young adults but slow across older age.

2.4. Nature affinity

Our second research question considered if nature affinity predicts changes in affect within the context of local, routine urban nature exposure. We found no significant main effect of self-expressed nature affinity in regression models of cognitive or affective outcome. Nature affinity was inversely related to duration spent green exercising under this study. Higher nature affinity predicted shortened duration of time outdoors for observed individuals, with mean duration reduced by 5.14 min (CI: −12.10, 1.82), $p = 0.15$) for each one-level affinity increment (1–7 range). Higher nature affinity also associated with increased frequency but shorter duration of green exercise. Individuals who expressed full level-7 affinity with nature spent on average 30 min/day, or 210 min/week, walking outdoors. In comparison, participants who expressed level-2 nature affinity spent a mean 55 min outdoors for this study but engage with nature less than monthly.

Table 3
Pre-intervention mood score indicators used in the fixed effects model show considerable variation by green exercise exposure duration. Fixed effect magnitude strongly reflects these baseline mood differences.

Duration time in minutes	Time 1 Mood score ± SD	Mood score difference ± SD	% Improvement mood score
< 30 min (N = 19)	50.60 ± 11.50	6.00 ± 7.52	17.00 ± 29.8
30–59 min (N = 31)	56.50 ± 9.38	4.85 ± 5.90	9.94 ± 13.2
> 60 min (N = 16)	45.30 ± 10.40	13.00 ± 10.30	34.40 ± 36.2

2.5. Changes in Mood

Our third research question asked if mood change is sensitive to urban green exercise, and if expectancy conditions this association. Mood models measured magnitude of within-person change using time 1 scores independent of exposure time. We assessed for mood change following green exercise under both fixed effects and random effects models. Results of fixed effects model for mean mood change following green exercise show being outdoors highly significantly influenced mood change (β = 0.54 (CI: 0.40, 0.67), $p < 0.001$), even after accounting for individual level variability in duration. Age 55 and older and suburban childhood were significant in adjusted Model 2 (β = 0.50 (0.34, 0.65), $p < 0.001$). Baseline mood scores differed notably among categories of anticipated exposure duration (Table 3), and these differences influenced the size and significance of post-intervention mood changes as shown in the fixed effects model (Table 4, Fig. 2a-b).

The random effects model revealed a significant association between all durations of green exercise and mean mood improvement, with those exceeding one hour outdoor walking time benefiting most strongly (Table 4, Model 1). The random effects model held more explanatory power over fixed effects, an outcome supported by the higher variability observed in the between-participants random slope. Bivariate tests of significance tests for the same ten independent covariables led to inclusion of categorical age, diabetes, and nature affinity in the adjusted mood model¸ though no variable held significant. Nature affinity neither influenced the significance of within-person mood change nor did it show an interaction effect with duration for mood change, in response to RQ 3.

3. Discussion

Our study assessed individual psycho-cognitive changes following a self-determined experience walking in a natural urban park or green campus. Self-directed outdoor exercise credibly captures the nature experience of many city dwellers and the health benefits they routinely derive in local greenspace. The US Department of Health and Human Services recommends moderate aerobic activity as a routine form of preventative healthcare and illustrates nearly exclusively this as green exercise in its Physical Activity Guidelines for Americans (Piercy et al., 2018).

Given its scope and untried design, our study produced some noteworthy results. Observed effect sizes approached or exceeded 10% at high significance levels, in line with other environmental intervention studies. We also detected some consistent, predictive signals influencing outcomes within a population whose size was unknown at study outset. Larger recruitment might confirm these signals within and across population subgroups.

In situ measures such as those taken here provide a deeper understanding of the associations between mood and outdoor exercise as they allow for real-time data assessment when physical activity and nature exposure most acutely effect mood while reducing the risk of recall bias. Having research subjects determine their own activity duration and walking pace in urban nature mollifies situational predictors, e.g., environmental context, and promotes external validity. The use of QR codes displayed on the recruitment table allowed for spontaneous enrollment and ease of uptake so that measured results truly indicated in situ effect. In addition, our study population for urban park usage was very heterogenous by age, education, and BMI, although campus participation slightly attenuated the racial diversity achieved at parks.

Brief intervals of urban nature exposure offer “instorative” potential for all age groups irrespective of stress recovery need (Gidlow et al., 2016; Hunter et al., 2019; Hartig, 2007). Olmsted expressly designed his parkscapes with intricate pathways inducing visitors to perambulate across their circulating layout for restorative outcome. The immediacy of urban park walks can impact productivity, information retention and mood elevation at many societal levels. Restored attention may be the

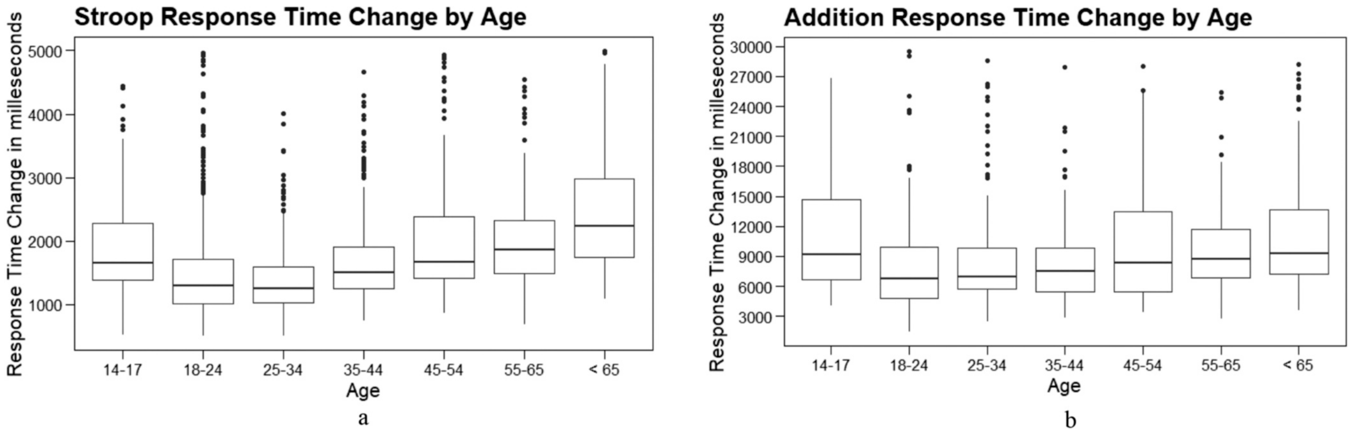

Fig. 1. a-b: Response for Stroop timing (1a) and ADD timing (1b).Cognitive test associates significantly across all age groups with improved timing of response, while slowing with advancement of age.

Table 4
Results of fixed effects model for mean mood change following green exercise show being outdoors makes a highly significant difference in mood change, even after accounting for individual level variability in duration. Effects measures, CIs, and p-values observed for mean mood changes based on regressions of differences in pre- and post-intervention MDMQ scoring.

Mood score change	Model 1[a]	p-value	Model 2[b]	p-value
Duration outdoors				
Intercept (< 30 min)	29.45 (22.31, 36.59)	< 0.001	28.87 (19.89, 37.85)	< 0.001
30–60 min	1.60 (−1.53, 4.72)	0.31	0.14 (−3.05, 3.33)	0.93
> 60 min	4.54 (0.36, 8.72)	0.03	4.44 (−0.61, 8.10)	0.09
Baseline MDMQ score	0.54 (0.40, 0.67)	< 0.001	0.50 (0.34, 0.65)	< 0.001

[a] Unadjusted model 1 effect measure: outcome ~ duration + (1|PID)
[b] Model 2 adjusted for duration, categorical age, childhood urbanicity and (1|PID)

mechanism responsible for improved executive functioning observed among nature-exposed preschoolers (Schutte et al., 2017). Academic improvements have been observed when learning in outdoor settings complements indoor instruction (Kuo et al., 2018; Mason et al., 2021; Otte et al., 2019; Mason et al., 2021). Nature-infused intervals might prove restorative in situations demanding long periods of directed attention in work, educational, and institutional settings, especially for younger schoolchildren. Workplace campuses, senior facilities, and school grounds could build nature-based infrastructure into their essential design and incorporate scheduled breaks supporting restorative attention or instorative wellbeing in nature.

3.1. Cognition

Our results extend previous research findings on the impact of outdoor exercise on cognition and uphold Kaplan (1995) theoretical proposal linking restoration of attentional fatigue to natural environments. Improvements for Stroop timing, Stroop throughput, and ADD response times were on par with findings from other studies of cognitive performance following environmental interventions. To compare, one study found percentage time change to complete for the Stroop Test following 30-minutes of aerobic exercise decreased by 10.2% for congruent color

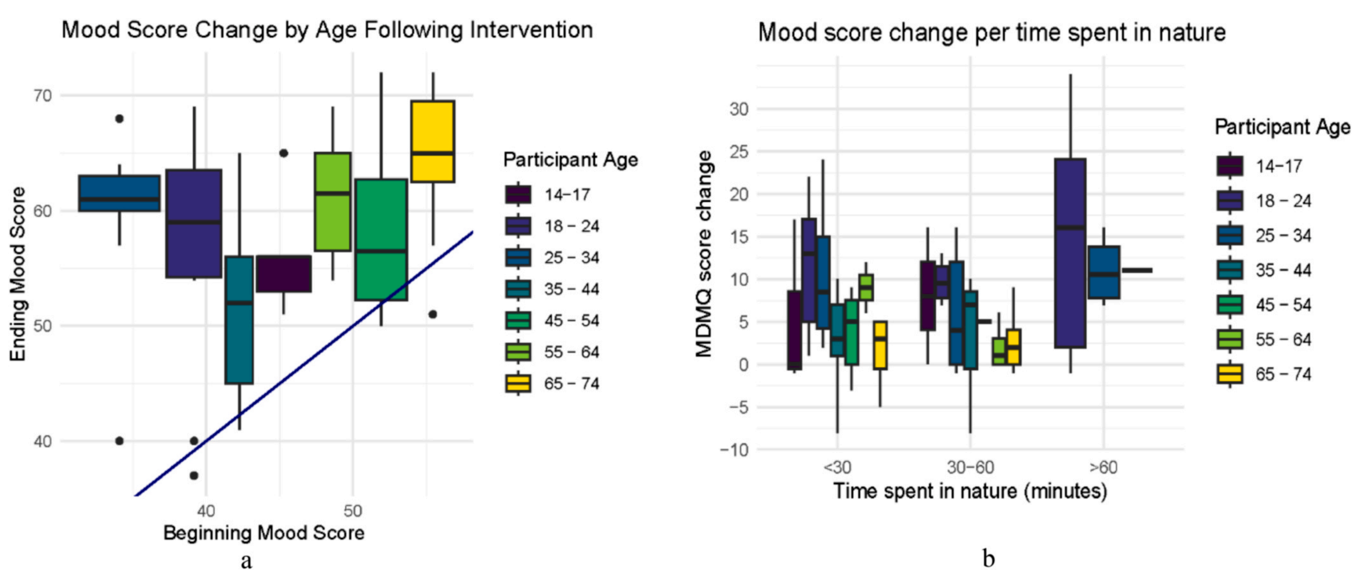

Fig. 2. a-b: Changes in Multidimensional Mood Questionnaire (MDMQ) score changes following nature intervention observed under this study arranged by age (2a) and by outdoor exposure duration (2b). Panel 2b shows that study participants who spent > 60 min in nature experienced significant increases in mood scores, especially true for the 18–24 age group, predominantly urban campus walkers with low baseline scores.

trials and by 20.6% for incongruent color trials (Tam, 2013).

The linear magnitude of effect seen in response timing improvements alone suggests that exposure duration had a larger effect on test speed than on test accuracy for Stroop and math deliberations. Nature contact impacts cognitive domains differentially (Mayer et al., 2009), making some tests more sensitive to the exposure variable. Our results further showed a possible saturation effect for three age categories 18–44 where speed of response no longer responded elastically to green exercise duration, creating an upper limit to cognitive improvement for these groups. In contrast, non-significant improvements in both Stroop timing and throughput were observed for individuals aged 65 and over, suggesting nature's high restorative potential for older adults.

3.2. Mood

Outdoor walking did not influence mood as a dose-response function, confirming prior research (Neill et al., 2019). Longer outdoor exposure and more negative incoming mood differentiated the results of young adults here from other age categories, providing valuable insights drawn from this heterogeneous study base. We discovered that post-intervention mood scores rose from baseline for all participants, yet only individuals exercising outdoors for an hour or more experienced significant mood improvements. Most individuals aged 18–34 fell into this group, compared to other age categories walking 20–50 min. Potential reasons for effect difference could likely be late-semester academic mental fatigue and sleep reduction among campus walkers. Sensitivity analyses we performed suggest that emotional and motivational expectations for outdoor exercise shaped baseline mood scores, establishing a priori the range of possible post-intervention mood changes.

3.3. Nature affinity and expectations for time in nature

Prior qualitative research conducted by this research team revealed that most nature users hold expectations that are conditioned by past outdoor experiences and personal nature affinity (Tomasso et al., 2022). We learned affinity is not immutable but responds to repetitive dosing over time. Individuals pattern their outdoor leisure experiences around subjective expectations, including anticipatory processing (More and Payne, 1978), making exposure duration and frequency useful between-person variables for measuring effect. For many, cumulative exposure to nature occurs in routine environments close to work or home, with self-determined dosing satisfying personal expectations. In this study, for example, we found employees of hospitals, professional firms, and cultural institutions bordering the parks routinely walked outdoors during work breaks, whereby older individuals and families explained their outdoor exercise habits and duration choices around expectations and intent.

Our study design revealed an unexpected pattern of physical activity duration aligned with nature affinity. Countering anticipations, we found higher self-described nature affinity predicted more frequent but briefer periods of outdoor leisure. Participants who expressed high nature affinity in this study averaged under 30 min per outdoor walk, medium affinity 38 min, and low affinity 55 min. Priming by nature affinity prior to outdoor exercise might be creating a learned psychological effect which influences urban nature exposure. The study also revealed some underlying relationships between duration and frequency but did not empirically pursue an "optimal" urban nature exposure duration, a concept heavily dependent on individual and exogenous factors.

This study fulfilled a secondary aim of testing field design and methods. Participant compliance with pre- and post-intervention survey completion and individual item response proved insightful for its clear socio-demographic patterning, especially by age. The ordering of the ADD before the Stroop test appeared to lower response compliance among young participants who may have embraced the game-like Stroop prompts versus math calculations and yielded more balanced cognitive sampling. Reversing the ADD and Stroop Tests or replacing the ADD test with an alternative cognitive assessment altogether might increase compliance in future study iterations. Prospective research building on this study should include a control group or randomized control trials where participants are assigned fixed outdoor walking times across several weeks to preserve within-person variability, accounting for physical ability.

3.4. Limitations

Findings on effect improvements are cautiously presented given the limitations that sample size and missingness cause. The sample size of completed cognitive tests lessened result reliability but indicated effect sizes worthy of investigating with a larger population. Patterned missing data also characterized the cognitive trials in our survey as nearly all minors but few older adults omitted the cognitive tests. The lack of a control group is a limitation, and random sampling would have strengthened study design. However, randomizing duration in nature was not feasible given in situ participant recruitment at the start of routine walking patterns began and different capacities for exercise intensity across longer durations. On-site participation was influenced by external factors such as time availability, interest, or alternate park egress which excluded some individuals who had already accrued outdoor exercise time prior to recruitment.

We use the term "urban green exercise" rather than "nature contact" to avoid misrepresenting this real-time park use intervention as any open-ended nature experience. We did not distinguish physical activity as an independent predictor or moderator of outcome as overlapping exposures of green exercise, nature contact, and social context made it difficult to disentangle independent predictors from observed effects in this study. Socialization was not modeled as an effect moderator despite having collected data on this, despite social support being known to mediate health enhancements from nature exposure (Maas et al., 2009; Staats and Hartig, 2004). We examined mood as a treatment effect related to duration of nature time through sensitivity analyses but not more formally as a component of outcome. Mediation analysis would be advisable in future studies to parse out the contribution of individual and combined exposures on outcomes.

4. Conclusions

This study offers evidence which complements previous studies findings to support cognitive improvement and limited mood change in a before-after green exercise intervention. Duration of self-chosen urban parks and campuses itself was influenced by subjective expectations, nature affinity and baseline affect. Our field research adds to the nature-health literature by associating duration of time in nature with effect magnitude in different population types. Given study strengths and limitation, the findings indicate that duration of outdoor exercise helps predict psychological and cognitive outcome. However, participant-established urban green exercise duration may also reflect underlying nature affinity and other unmeasured variables such as positive motivation toward outdoor exercise and perceived restorative need as conditioned by previous learned experiences in nature, factors deserving further investigation.

5. Material and methods

5.1. Site selection

We selected two urban nature settings near Hartford, Connecticut for their demographic heterogeneity among prospective participants. Both public parks are in census tracts of low mean SES and offer a diverse sociodemographic base. One contains small, picturesque water features, and both interior meandering pedestrian pathways (Fig. 1a-c) and are well-maintained and highly frequented. The addition of two urban campuses in Hartford and Boston with proximate urban greenspace expanded the study sites. All sites were designed by Olmsted Studio between 1870 and 1897 (Fig. 3).

5.2. Study population

The study population (N = 82) consisted of urban walkers randomly recruited at two parks located in cities of high population diversity. The research team conducted voluntary recruitment at the park entrances. 66 individuals successfully completed pre- and post-surveys for mood, 60 for addition test, and 59 for the Stroop test. Seventeen undergraduate and graduate students also were recruited into the study at urban campuses. Criteria excluded individuals under age 14 or diagnosed with color blindness, which would prevent completion of the color-based Stroop test. English-speaking was not an inclusion criterion. Table 5 provides descriptive statistics on participants who self-selected into the study.

5.3. Study tools

An interactive research instrument designed specifically for this study comprised pre- and post-nature immersion surveys administered through the Qualtrics data collection platform. QR codes linked the survey platform directly to participants' smartphones or to the research teams' iPads for those without a mobile device (Supplemental Figs 1 and 2).

Cognitive response was assessed through two sets of repeated measures. The Stroop color-word test evaluates the ability to filter information and suppress habitual response as a measure of executive attention and inhibitory control. A two-digit, visual addition–subtraction (ADD) test evaluates cognitive speed and working memory. Identical prompts appear in rapid succession for the Stroop and ADD tests in both the pre- and post-intervention surveys, totaling two minutes. Stroop and math timing tests are measured in milliseconds, with a negative score indicating the participant's speed of response improved following the outdoor walking intervention. Prior assessment demonstrated the sensitivity of these cognitive function tests to environmental quality parameters (Cedeno-Laurent et al., 2018).

Stroop test metrics include response time, inhibitory response time (i.e., the difference in response times between congruent and incongruent trial times), and throughput (number of correct responses per minute) Actual color names (e.g., blue, red) alternate with random words (e.g., taxi, flower) on the screen. By selecting the first letter of the ink color (g-b-r-y) rather than the first letter of the word printed in incongruent ink colors appearing on the screen (Stroop, 1935), the Stroop Effect captures the interference factor of "conflicting word stimuli delay" (Hanslmayr et al., 2008; Larson et al., 2009). The process of recognizing colors is less automatic than reading words and typically requires more cognitive attention and longer response times to process one stimulus while suppressing another. Response times are recorded in milliseconds for each of 25 visual prompts. Scoring reflects individual reaction times of the pure Stroop test ("yellow" in yellow ink) less the time recorded for interference ("yellow" in red ink) as a measure of filtering out dissonance arising between viewed word meaning and viewed ink colors (MacLeod, 1991).

Table 5
Random effects model for mean mood change following green exercise, showing effects measures, CIs, and p-values observed. All durations in this study significantly relate to positive mood changes under Model 1 and significant or marginally significant positive changes under the adjusted Model 2. The intercept in the random effects model accounts for random variability in baseline mood across the participant sample.

Mood score	Model 1[a]	p-value	Model 2[b]	
Duration outdoors				
Intercept (Baseline)	46.92 (41.07, 55.66)	< 0.001	48.43 (40.79, 56.08)	< 0.001
< 30 min	6.16 (2.99, 8.23)	0.037	5.63 (2.84, 8.42)	< 0.001
30–60 min	3.27 (0.19, 6.34)	0.005	3.13 (−0.35, 6.61)	0.08
> 60 min	7.08 (0.09, 14.07)	0.016	7.09 (−0.26, 14.44)	0.06

[a] Unadjusted model 1 effect measure: outcome ∼ duration + (1|PID)
[b] Model 2 adjusted for duration, categorical age, Type 2 diabetes, nature affinity, and (1|PID)

The ADD assessment features 11 mathematics prompts solvable at an eighth-grade education level: eight two-digit addition problems and three one- and two-digit subtraction problems. ADD test metrics include response time and throughput.

To assess change in mood, we chose the 12-item Multidimensional Mood Questionnaire (MDMQ), a validated psychological assessment with high internal consistency (Cronbach's alpha = 0.91) (Wilhelm and Schoebi, 2007). Participants rate current mood qualities on a 1–6 Likert scale of (1 = definitely not, 6 = extremely) before and after green exercise: "At this moment I feel: tired–awake, content–discontent, agitated–calm, full of energy–without energy, unwell–well, relaxed–tense." The MDMQ total score index (maximum score = 72) was the dependent variable for repeated measures mood change.

The pre- and post-intervention surveys each contained the mood survey (MDMQ), the ADD, and Stroop tests in this order. The post-survey also gathered information on the individuals' specific nature experience measured in this study (binary variables: active or resting, alone or accompanied; satisfaction with site and duration of urban nature visited (1–10 scale, 10 being fully satisfied); typical frequency and duration of routine nature exposure (1–5 categorical scale); and nature affinity measured by the Inclusion of Nature (INS-7) scale (Schultz, 2002). Baseline sociodemographic information (age, gender, race/ethnicity, education, childhood and current urbanicity), self-reported health profiled on the composite short-form SF-12 Physical and Mental Health Summary (Ware et al., 1998), and additional Y/N questions about doctor-diagnosed hypertension, diabetes, pregnancy, smoking/vaping, and self-reported heightand weight to derive Body Mass Index (BMI) classified according to CDC gender-specific percentile cut-offs

Fig. 3. a-c: Study sites from left: 3a) Elizabeth Park, Hartford, CT; 3b) Walnut Hill Park, New Britain, CT; 3c) Emerald Necklace, Boston, MA.

completed the questionnaire.

5.4. Data collection

The study was conducted during mid- to late-fall 2021 to avoid excessive ambient temperature. Weather conditions—sunny or partly sunny, 60–70° F—were unchanged across study days. Non-consecutive recruitment days included one weekday federal holiday, two late weekday afternoons, and one early weekend afternoon to capture different park users. The research team recorded walking duration for each participant as the time the post-survey began less the time the pre-survey was completed.

Adult participants consented electronically to participate in the study at time of enrollment and were assigned an anonymous participant ID. Parents of participants aged 14–17 provided consent and minors their assent in accordance with IRB restrictions. Pre- and post- surveys were matched on participant ID, and no individual identifying information was retained. Upon completing the post-intervention survey, participants received a $20 gift card to acknowledge their time. The Harvard T.H. Chan School of Public Health Institutional Review Board approved the study under IRB 21–0967 on 9 August 2021.

5.5. Analytical approach

This field study used a repeated measures design to assess within-subjects changes. Participant ID was treated as a nested random effect to account for the unexplained population heterogeneity and expected correlation between measurements taken from the same individual. Within-person variables included mood scores, cognitive responses, and trial number of cognitive tests. Intervention duration, socio-demographic variables, nature affinity, and routine green exercise frequency served as between-person variables (Fig. 4).

Separate tests were run on the Stroop data to compare within-subject effects in a) speed of processing response to visual tasks, measured in milliseconds, b) automaticity of response suppressed by interference between incongruent and congruent color-word trials, i.e., the Stroop Effect, and c) throughput measuring the rate of correct response per minute. Separate timing and throughput tests were similarly run on the ADD data. Repeated measures to assess changes in Stroop, addition, and mood outcomes were analyzed through linear mixed effects modeling and generalized linear models using the R lme4 package version 1.1–14 (Bates et al., 2015). Separate models were systematically assessed with Chi-squared tests to test for significance of each independent covariable (hypertension, categorical age, gender, race/ethnicity, education, childhood urbanicity, current urbanicity, smoking, BMI, and nature affinity) which possibly contributed to predict dependent variables.

Degrees of freedom and p values using Satterthwaite approximation were calculated using the R package lmertest (Kuznetsova et al., 2017). Shapiro-Wilkes tests showed the predictor variables for the Stroop and ADD outcomes to be normally distributed. Regression estimates were performed as mixed effects models, with the random component representing the individual participant profile. Intercept and slope were conceived as varying randomly. A significance test of α level $p < 0.05$ examined the influence of the main predictor variable, duration of time walking outdoors measured in minutes. All statistical analyses were performed with R version 4.0.2 (R Core Team, 2020).

Funding

The Department of Environmental Health's research on nature exposure and health at the Harvard Chan School of Public Health was supported by the REI Cooperative. LPT additionally received training support from the NRSA T32-ES007069.

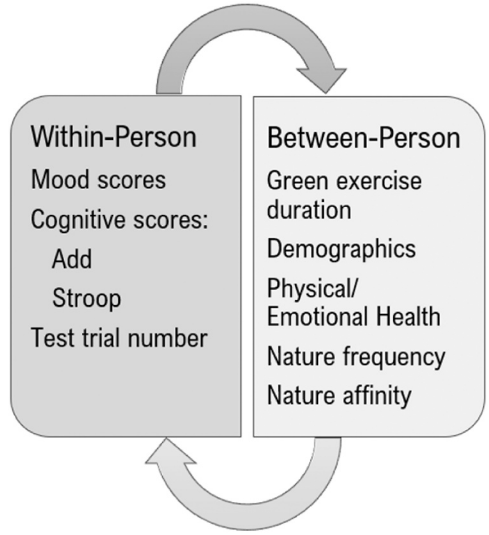

Fig. 4. Within-person vs. between-person variables to assess within-subject changes following urban nature walking.

CRediT authorship contribution statement

Linda Powers Tomasso: Conceptualization, Methodology, Software, Investigation, Formal analysis, Data curation, Writing – original draft, Visualization, Project administration. **John D. Spengler:** Methodology, Formal analysis, Writing – review & editing, Supervision, Funding acquisition. **Jarvis T. Chen:** Methodology, Formal analysis, Writing – review & editing, Visualization. **Paul Catalano:** Methodology, Formal analysis, Writing – review & editing. **Jose Guillermo Cedeno Laurent:** Conceptualization, Methodology, Software, Formal analysis, Writing – review & editing, Supervision, Project administration. All authors have read and agreed to the published version of the manuscript.

Declaration of Competing Interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Linda Powers Tomasso reports financial support was provided by National Institutes of Health.

Acknowledgements

The authors thank Susan Masino for allowing us to present this study design at Trinity College, Hartford.

Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.ufug.2023.128005.

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