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The effect of green walking on heart rate variability: A pilot crossover study

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Abstract

We investigated the effects of regular walking in green and suburban environments on heart rate variability (HRV) and blood pressure (BP) in middle-aged adults. Twenty-three adults participated

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Author contributions

JNB conducted research, analyzed data, and wrote manuscript. ZCP assisted in conducting research and wrote manuscript. JNB, IES, JML, THH and MAP designed the research protocol. MAP critically revised the manuscript. ZCP, NAM, and MAP assisted on data analyses. All authors reviewed and approved the final manuscript.

The Institutional Review Board (IRB) of the University of Minnesota approved all study procedures. Following a detailed explanation of study procedures, informed consent was obtained from all participants prior to baseline data collection. All procedures performed with participants were in accordance with the ethical standards of the University of Minnesota IRB and with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards.

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Conflict of interest

Authors have no conflicts of interest to report.

in a non-randomized crossover experiment comprised of once-weekly 50-min moderate-intensity walking sessions. Separated by a two-week washout period, participants walked for three weeks in each of two treatment conditions (green and suburban) in a local arboretum and suburban sidewalks of Chaska, MN. Eleven participants completed green walking first and 12 suburban walking first. Walks were split into 15-min intra-walk phases, with phases representing each walk's beginning, middle, and final 15-min. Repeated measures linear mixed models evaluated (1) HRV phase differences between treatments and HRV change within treatments, and (2) pre- and post-walk BP differences between treatments and pre- to post-walk BP changes. Intra-walk phase analyses revealed higher HRV during green walking vs. suburban walking during phase 2 ($p < 0.0001$) and phase 3 ($p = 0.02$). Less HRV reduction was seen between intra-walk phases 1 and 2 during green vs. suburban walking ($p = 0.02$). Pre- to post-walk changes revealed decreased mean systolic BP for both green ($p = 0.0002$) and suburban ($p = 0.003$) walking conditions, but not for diastolic BP. Post-walk BP results were similar after both green walking and suburban walking. In summary, walking sessions in a green environment elicited greater beneficial HRV responses compared to a suburban environment. Additionally, walking in either environment, green or suburban, promoted reductions in systolic BP.

Keywords

greenspace; suburban environment; physical activity; heart rate variability; blood pressure

1. Introduction

Autonomic nervous system (ANS) dysfunction has been associated with poor cardiovascular health. Briefly, the parasympathetic nervous system (PNS) and the sympathetic nervous system (SNS) are responsible for maintaining proper ANS influence on the heart. PNS influence is heightened when an individual is in a more relaxed state, while SNS influence increases when an individual is in a state of excitement or stress.¹ PNS-SNS balance can be measured via heart rate variability (HRV)—a non-invasive measure of the influence of the PNS and SNS on the heart.^{2,3} Higher time-domain measures of HRV are considered better (i.e., greater variation in the time between heart beats), with lower HRV (i.e., smaller variation in the time between heart beats) related to increased risk of sudden cardiac death,⁴ atherosclerotic plaque progression,⁵ congestive heart failure,⁶ coronary heart disease,^{7,8} stroke,^{9,10} and myocardial infarction.^{11,12} Notably, regular physical activity participation (i.e., exercise) is known to improve HRV. Randomized trials and epidemiologic studies have suggested that exercise leads to improved time- and frequency-domain HRV parameters in healthy^{13–16} and clinical populations (e.g., individuals with diabetes mellitus¹⁷ and heart failure^{18,19}) compared to their less active counterparts.

Human interactions with nature (i.e., nature-based green environments) have been linked to numerous positive physiological health outcomes.^{20–22} In a recent systematic review and meta-analysis, interactions with nature were associated with improved HRV, lower cortisol production, and decreased risk of type 2 diabetes.²³ To date, however, evidence remains inconclusive about how the environment might interact with exercise to promote beneficial cardiovascular responses and, more specifically, the cardiovascular responses characterizing

HRV and blood pressure.^{24,25} Studies of green exercise (i.e., exercise in nature-based green environments)²⁶ have suggested that exercise in green environments results in greater improvements in cortisol²⁷ as well as blood pressure (BP) and heart rate,²⁸ compared to exercise completed in urban environments. A study of HRV in young adult males suggested a single session of forest walking improved HRV indices relative to a single session of urban walking²⁹, but little research on this topic has been conducted in other populations. Walking in settings that are more suburban or urban areas may induce greater psychosocial stress while also exposing individuals to greater amounts of environmental pollutants (e.g., air and noise pollution) vs. greener environments; all of which may have the effect of lowering HRV and increasing BP.^{30–33}

Investigating the difference in cardiovascular responses between green environments and suburban environments, the latter representing where middle-aged adults are most likely to live, is important in understanding the benefits of green exercise and the development of green exercise prescriptions for middle-aged adults to prevent or attenuate cardiovascular disease progression. Such studies may assist in not only describing the benefits of green exercise, but also in supporting the advocacy for greenspace conservation to improve use of green areas for physical activity and promote community-level health.³⁴ The purpose of this crossover study was to experimentally investigate the effects of repeated moderate-intensity walking sessions completed in green and suburban environments on the HRV and BP of middle-aged adults. Given nature's demonstrated ability to reduce stress and cortisol levels, and improve mood,^{35–38} as well as the known BP-lowering effects of exercise,³⁹ we hypothesized that green walking relative to suburban walking would result in: (1) higher time-domain HRV measurements during predetermined phases of the walk; (2) less HRV reduction throughout the course of the walk; and (3) greater pre-post BP reductions after the walk.

2. Methods

2.1 Participants

Twenty-four middle-aged adults (20 females; mean \pm SD: 49.3 \pm 6.7 years) were recruited for this study. Prospective participants underwent study screening against the following inclusion criteria: (1) aged 35–59 years; (2) not currently taking anti-anxiety or anti-depressant medications; (3) not having diagnosis of, and/or taking medication for, a chronic disease; (4) having no contraindications to moderate-intensity walking; and (5) not currently meeting the recommended levels of weekly physical activity (i.e., 150 min/week)³⁹. Study procedures were approved by the Institutional Review Board (IRB) of the University of Minnesota, with the study registered on [clinicaltrials.gov](https://clinicaltrials.gov/ct2/show/study/NCT03442998) (NCT03442998). Following a detailed explanation of study procedures, informed consent was obtained from all participants prior to baseline data collection. All procedures performed with participants were in accordance with the ethical standards of the University of Minnesota IRB and with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards.⁴⁰ Participants were compensated on a prorated basis up to \$200.00 US for study participation.

2.2 Study Design

This study was a 9-week crossover trial in which all participants were asked to participate in both of the following treatments: (1) green walking: walking on unpaved and secluded nature trails of a local arboretum; and (2) suburban walking: walking on paved sidewalks of medium traffic roads located in a medium-density residential area. Each treatment was three consecutive weeks in duration and completed once a week on the same day and time. A two-week washout period (i.e., no study walking) separated treatments (see Figure 1). Given limited study resources, participants could not be randomized to the two conditions and tested simultaneously. Therefore, the first 12 participants recruited were assigned the following treatment sequence: green walking then suburban walking. The next 12 participants were assigned to the opposite treatment sequence: suburban walking then green walking.

2.3 Environmental Settings

For the green walking condition, we chose a walking path at a nature preserve, with a richness in vegetation and greenness. This location was situated conveniently about 40 kilometers southwest of the St-Paul-Minneapolis, MN metropolitan area. More specifically, participants walked at the Wood Duck Trail of the Minnesota Landscape Arboretum (MLA), which is approximately 1.6 kilometers long. This trail was unpaved, secluded by tall trees and shrubs, contoured a pond, and had minimal inclination. The MLA is part of the University of Minnesota and has more than 1,200 acres of gardens, woods, and prairies in addition to several kilometers of trails. The suburban walks occurred on paved sidewalks approximately three kilometers away from the MLA's trail, adjacent to medium traffic roads located within a medium-density residential area (town population of ~27,000 residents) and had minimal inclination and few intersections. All participants walked in both green and suburban settings and in the same pre-specified paths.

2.4 Measures

2.4.1 Demographics—At the baseline visit, participants were first consented and then administered a demographic questionnaire for date of birth, sex, and measures of socioeconomic status (i.e., household income, employment status, education).

2.4.2 Anthropometrics—Weight and body fat percentage were measured on a calibrated electronic Tanita TBF-300A Body Composition Analyzer scale (Tanita Corp., Tokyo, Japan) to the nearest 0.1 kg and 0.1%, respectively. Height was measured with a stadiometer (model 437; Seca, Hamburg, Germany) to the nearest 0.1 cm. Body mass index (BMI) was calculated from the weight and height measurements and reported in kg/m². Participants were measured while wearing light clothing and no shoes.

2.4.3 Heart Rate Variability—HRV was measured using the Zephyr BioHarness™ 3 (Zephyr Technology Ltd., Auckland, New Zealand)—a chest-mounted apparatus which has been validated.^{41–43} This apparatus ('BioHarness') measured HRV at a sampling rate of 250 Hz, with HRV calculated on a rolling 300-second basis. HRV measurements were reported as standard deviations of normal-to-normal RR intervals (SDNN) in milliseconds (ms)—a time-domain measurement which characterizes overall HRV.³ Research assistants moistened

the electro-sensing pads and placed the BioHarness around each participant's chest, and situated the BioHarness's data collection unit (i.e., the BioModule) on the participant's left side along the mid-axillary line. The BioHarness also collected data on heart rate (HR) and activity intensity (measured in g-forces; 0.20 g indicative of moderate-intensity walking). HRV, HR, and activity data were collected prior to, during, and after each walk and these data were downloaded and imported into Zephyr's OmniSense Analysis program immediately after each participant's walking sessions.

2.4.4 Blood Pressure—Participants sat with feet flat on the floor and legs uncrossed for at least five minutes before BP was measured. A HEM-705CP automatic blood pressure monitor (OMRON, Omron Healthcare Co., Ltd., Kyoto, Japan) measured BP, with the cuff placed on the upper left arm. Systolic and diastolic BP in millimeters of mercury (mmHg) were measured three times before and after each walk and the average of these measurements used for analyses.

2.5 Procedures

Participants arrived at each walking session in a fasted state (6+ hrs.). To calibrate the BioHarness, participants were asked to engage in five and two minutes of sitting and standing, respectively. Blood pressure measurements were subsequently taken following five minutes of quiet rest. Before starting each walk, participants were offered light snacks to break up fasting, and given a stopwatch to time their walks as the use of smartphones and/or smart devices (e.g., smartwatch) was prohibited to avoid distracted walking and facilitate engagement with the environment. The participants were asked to walk alone continuously for 50 minutes and were encouraged to observe their environment (e.g., flora and fauna) and to stop as needed (e.g., at crosswalks, to tie an untied shoe). Although walking speed was participant-controlled, running and/or jogging were not allowed. After returning from each walk, participants were asked once again to engage in five and two minutes of sitting and standing, respectively, per BioHarness protocol, with BP measured after another five minutes of quiet rest. Finally, the BioHarness was taken off each participant, turned off, and data downloaded immediately for later processing.

2.6 Statistical Analysis

We first inspected all data for physiological plausibility and potential data recording/entry errors, followed by normality testing. HRV, HR, and activity data from each walking session were split into three intra-walk phases, with the first, second, and third phases representing each walk's first 15, middle 15, and final 15 minutes, respectively. We chose this 15-minute intra-walk phase length to ensure that the greatest amount of data during each walk for each participant could be analyzed when accounting for shorter walking times (shortest walk on record: 47 minutes). Two-minute pre- and post-walk sitting phases for HRV and HR were also defined. Congruent with the HRV literature, we adjusted for HR in our HRV analyses at rest and during each walking session.

We employed a repeated measures linear mixed model approach using PROC MIXED in SAS version 9.4 (SAS Institute Inc., Cary, NC). The statistical model treated each participant as a random effect and treatment (green vs. suburban), period, and sequence

(green then suburban vs. suburban then green) as fixed effects. This model can be presented mathematically as:

$$Y_{ijkl} = \mu + \delta_l + \beta_{i(l)} + \alpha_j + \gamma_k + \varepsilon_{ijkl}$$

where Y_{ijkl} is the outcome due to participant i , treatment j , period k , and sequence l measured at a specific time (walk week), with μ being the intercept, δ_l the sequence, $\beta_{i(l)}$ the random effect due to participant i nested within sequence l , α_j the treatment, γ_k the period, and ε_{ijkl} the random error. Period was included due to the fact we were unable to randomize participants into a treatment sequence and thus needed to adjust for period effects.⁴⁴ HRV during each intra-walk phase and the pre- and post-walk phases, as well as HRV change between phases, were modeled separately as dependent variables, and treatment, period, and sequence as independent variables. HR was also included in the preceding model as a continuous covariate. A compound symmetry structure was used to model correlations between repeated measurements over time as this structure demonstrated the smallest Akaike information criterion (AIC) value. Differences between conditions were evaluated using Tukey-adjusted least-squared means with 95% CIs. Analyses of pre- and post-walk BP differences, as well as pre- to post-walk BP changes, were analyzed using the same model parameters and structure as specified above, with the only difference being that HR was not a covariate in these analyses. We did not perform formal sample size and power calculations for this pilot study, given that our objective included the assessment of intervention trends in outcome measures and feasibility. Therefore, as suggested in previous literature,⁴⁵ the analytical sample size of 23 was considered adequate.

3. Results

A modified CONSORT participant flow diagram is shown in Figure 2. One participant dropped out after signing the consent form and was therefore excluded from analyses. Another participant discontinued during the washout period for reasons unrelated to the study but was included in the analyses per intention-to-treat (ITT).^{46,47} Table 1 presents participant characteristics. The sample was comprised of mostly middle-aged females who were obese, had at least some college-level education, and somewhat elevated resting BP.

3.1 Heart Rate Variability

Figure 3 presents mean HRV for green and suburban walking conditions across intra-walk phases. Results revealed a somewhat higher mean HRV during the first intra-walk phase for the green walking relative to suburban walking ($p = 0.4$). Additionally, higher mean HRV during green walking vs. suburban walking during the second (31.0 ± 1.4 vs. 22.6 ± 1.4 , respectively; $p < 0.0001$) and third (33.2 ± 3.0 vs. 24.3 ± 2.9 , respectively; $p = 0.02$) intra-walk phases were observed. Within-walking condition HRV changes between first and second intra-walk phases revealed a greater mean HRV decrease during the suburban walking condition (-13.0 ± 2.0 ; $p < 0.0001$) compared to the green walking condition (-7.0 ± 2.1 ; $p = 0.001$). Similarly, within-condition HRV changes between the first and third intra-walk phases showed slightly greater mean HRV decrease during the suburban walking condition (-11.6 ± 1.8 ; $p < 0.0001$) relative to the green walking condition (-8.7 ± 1.9 ; $p <$

0.0001). Changes within-condition between the second and third intra-walk phases showed a slight increase in HRV during the suburban walking condition (1.5 ± 1.0 ; $p = 0.1$) compared to the green walking (-1.7 ± 1.1 ; $p = 0.2$).

3.2. Blood Pressure

Table 2 presents pre- and post-walk mean systolic and diastolic BP by green and suburban conditions. Pre-walk systolic and diastolic BP were similar between conditions. Pre- to post-walk changes revealed similarly decreased mean systolic BP for both green (-3.5 ± 0.9 mmHg; $p = 0.0002$) and suburban (-2.8 ± 0.9 mmHg; $p = 0.003$) walking conditions. As expected physiologically, diastolic BP changed minimally during the walk. Post-walk results revealed similar mean systolic BP (mean difference: -0.1 , 95% CI $[-1.9, 1.7]$) and mean diastolic BP (mean difference: 0.2 , 95% CI $[-1.2, 1.7]$) for green walking relative to suburban walking.

4. Discussion

Our observations suggested that green walking exercise resulted in higher HRV and less HRV reduction compared to suburban walking exercise, after adjustment for HR. These observations were consistent with our first and second hypotheses, respectively. Exercise is known to improve cardiac autonomic regulation by lessening sympathetic and enhancing parasympathetic influence,^{48,49} with improved HRV indices associated with improved cardiovascular health and outcomes.^{4,7,10,50} Empirical literature has also revealed the consistent beneficial health effects moderate-intensity exercises like walking have among clinical populations with previous myocardial infarction,¹¹ chronic heart failure,⁵¹ angina pectoris,⁵² and diabetes mellitus.⁵³ Despite these benefits, few studies have investigated how different environmental exposures influence HRV during walking exercise. For example, prior studies have observed that sitting and/or walking in nature environments—termed “forest bathing”—elicited higher HRV compared to sitting and/or walking in city environments.⁵⁴ Controlled indoor experimental studies have also noted increased HRV after viewing nature-based pictures compared to viewing pictures depicting urban environments.^{55,56} Similar to our study, a two-day field experiment with young adult males reported that a 15-minute self-paced forest walking session elicited greater PNS activity and lower SNS activity—resulting in improved HRV—compared with an urban walking session.²⁹

Our results may be indicative of two mechanisms. First, walking in suburban or urban areas (i.e., grayer environments) may induce greater psychosocial stress relative to walking in greener environments, with decrements to HRV associated with environmentally-induced stress or anxiety.³⁰ Second, walking in grayer environment may expose individuals to greater amounts of environmental pollutants vs. greener environments. Air pollution has been established as particularly influential on physiological stress responses. Indeed, air pollutants interact with specific receptors in the lungs and vasculature in a manner that increases SNS activity, thus lowering HRV, while also increasing systemic inflammation that may result in higher BP.^{31–33,57} Neither of the preceding outcomes is desired. Taken together, it would appear that exercise in green environments may benefit ANS and vascular functioning beyond that of exercise completed in urban and suburban environments. In

middle-aged adults with conditions such as prediabetes or diabetes that result in impaired autonomic and vascular functioning,^{58,59} green exercise may be beneficial in lessening the negative health impact of these conditions. Future studies should investigate how these environments' inherent characteristics (e.g., visual and olfactory stimuli, air quality) may impact psychosocial (e.g., anxiety, stress) and physiological (e.g., blood glucose control) mechanisms and determine whether and/or how these factors contribute to improved HRV.

Results indicated notable pre- to post-walk systolic blood pressure reductions within both walking conditions but not between walking conditions. While these reductions were encouraging and aligned with known blood pressure-lowering effects of exercise, the lack of between condition differences was incongruent with our third hypothesis and the mechanistic pathways previously mentioned. These observations were unable to support Pretty et al.'s⁶⁰ findings that exercise while viewing green environments led to greater blood pressure reductions relative to exercise completed while viewing built environments (i.e., urban settings)—similar to observations made by Park et al.⁵⁴ Congruent with our results, Lee and colleagues²⁹ observed decreased systolic blood pressure in young adult males from pre- to post-walk when completing one forest and urban walking session each but no difference between walking environments. These latter observations and the current study's findings are aligned with literature which has previously suggested that exercise leads to clinically meaningful systolic blood pressure reductions in adults regardless of the exercise environment.⁶¹ Further investigation should aim to comprehensively measure other factors that might also affect blood pressure (e.g., air and noise pollution) in order to determine potential environmental effects on blood pressure parameters.

The present study extends the paucity of green exercise literature in at least two ways. First, our study was conducted among middle-aged adults who were, on average, obese and had somewhat elevated blood pressure. Younger and normal weight participants, and with cardiometabolic profiles within the recommended ranges typically comprised the population samples of past studies on this topic. Having less restrictive inclusion criteria allowed us to include in our sample more middle-aged overweight adults with somewhat elevated blood pressure, who were more likely to benefit from the positive effects of green walking relative to healthier populations. Second, our study noted differences in HRV between green and suburban environments as opposed to between green and urban environments. Given the smaller differences in 'greenness' between green and suburban environments relative to between green and urban environments, our findings add to the literature which has shown the distinct health benefits of nature-based green environments on health. Future studies are needed to continue discerning where these differences arise.

The current study has several strengths. First, to our knowledge, this is the first study that investigated the effects of repeated once-weekly, 50-minute moderate-intensity walking sessions in green and suburban environments on HRV and blood pressure in middle-aged adults. Second, this study used a balanced and uniform crossover design, with a two-week washout period between treatment arms. This design and the implementation of the washout period enhances the level of statistical precision and power for model parameter estimates that can be obtained from small samples in addition to minimizing any potential carryover effects. Third, the chosen exercise modality (i.e., walking) is easily accessible, low impact,

inexpensive and thus readily incorporated into people's daily routines. However, there are limitations to this study. First, we did not perform simultaneous random assignment to treatment sequences. However, the crossover experiment is a type of self-matched design (i.e., each participant served as his or her own control) that reduces considerably the possibility of confounding and increases statistical precision for effect estimates.⁶² Second, the study sample is limited in generalizability as it was comprised of mostly women of middle - to high-income sampled from a single geographic area. Third, our study results are likely only generalizable to green and suburban settings with similar characteristics as the walking paths chosen for this study. Fourth, because we designated this investigation as a small pilot trial, we were not powered for, nor did we identify, *a priori* effect modifiers for analysis. Future larger and well-powered trials should consider identifying and examining *a priori* effect modifiers (e.g., participants' residential level of greenness) to enhance our understanding of the examined relationships.

5. Conclusions

This crossover study examined the effects of repeated walking sessions in green and suburban environments on HRV and blood pressure in a sample of middle-aged adults. Results suggested that 50-minute moderate-intensity walking sessions in a green environment elicited greater beneficial HRV responses compared to a suburban environment. Additionally, walking in either environment, green or suburban, promoted reductions in systolic blood pressure. Given these observations, future studies are needed to explore the longer-term interactive effects of walking exercise in green and other outdoor environments (e.g., grey, blue) on HRV, blood pressure, and additional cardiometabolic markers. Replication of our findings along with current green exercise literature discoveries might foster the development of not only nature-based green exercise prescriptions for disease prevention but also to the continued advocacy for greenspace conservation— particularly within more suburban or urban environments.

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Abbreviations:

HRV	Heart rate variability
BP	blood pressure
ANS	autonomic nervous system
PNS	parasympathetic nervous system

SNS sympathetic nervous system

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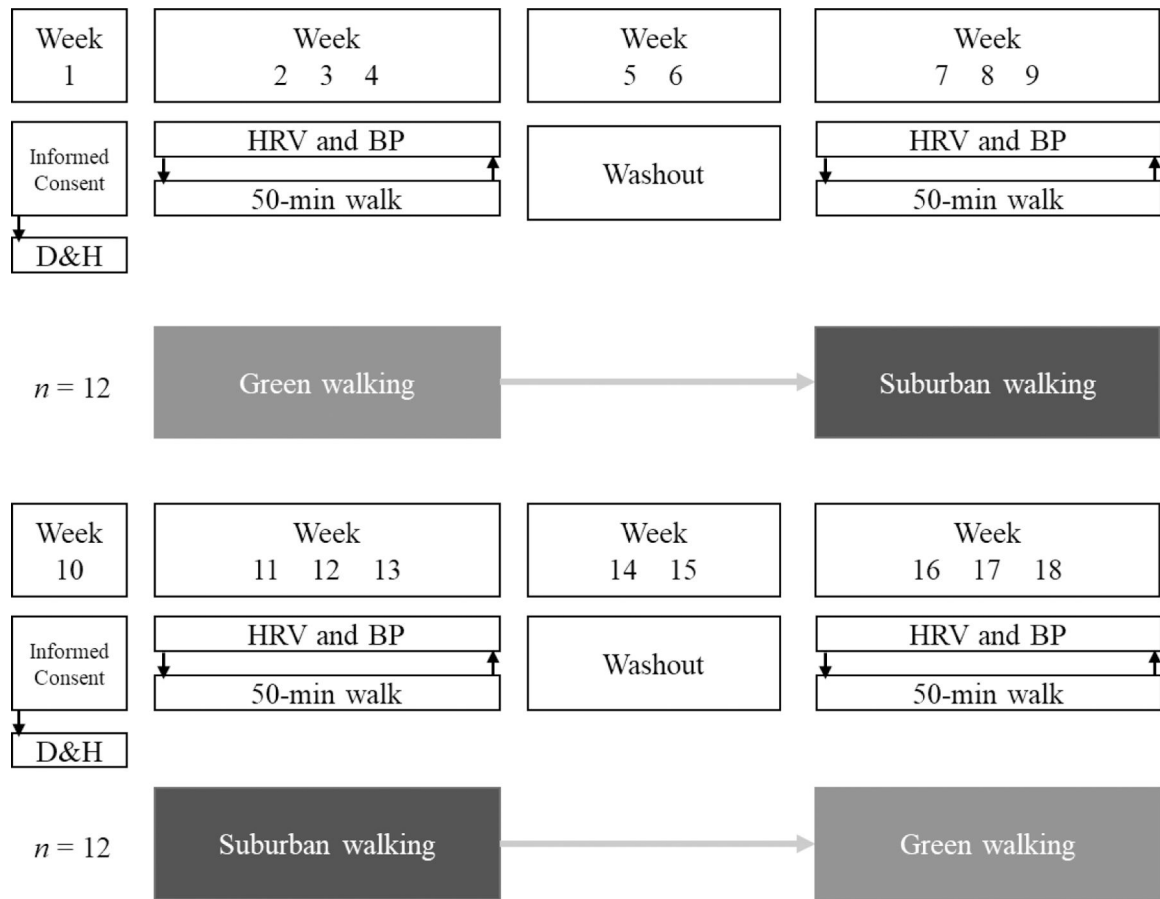


Fig. 1. Study design. <<1.5-column fitting image>>

Note. D&H, Baseline demographic and health assessment; HRV and BP, heart rate variability and blood pressure assessment.

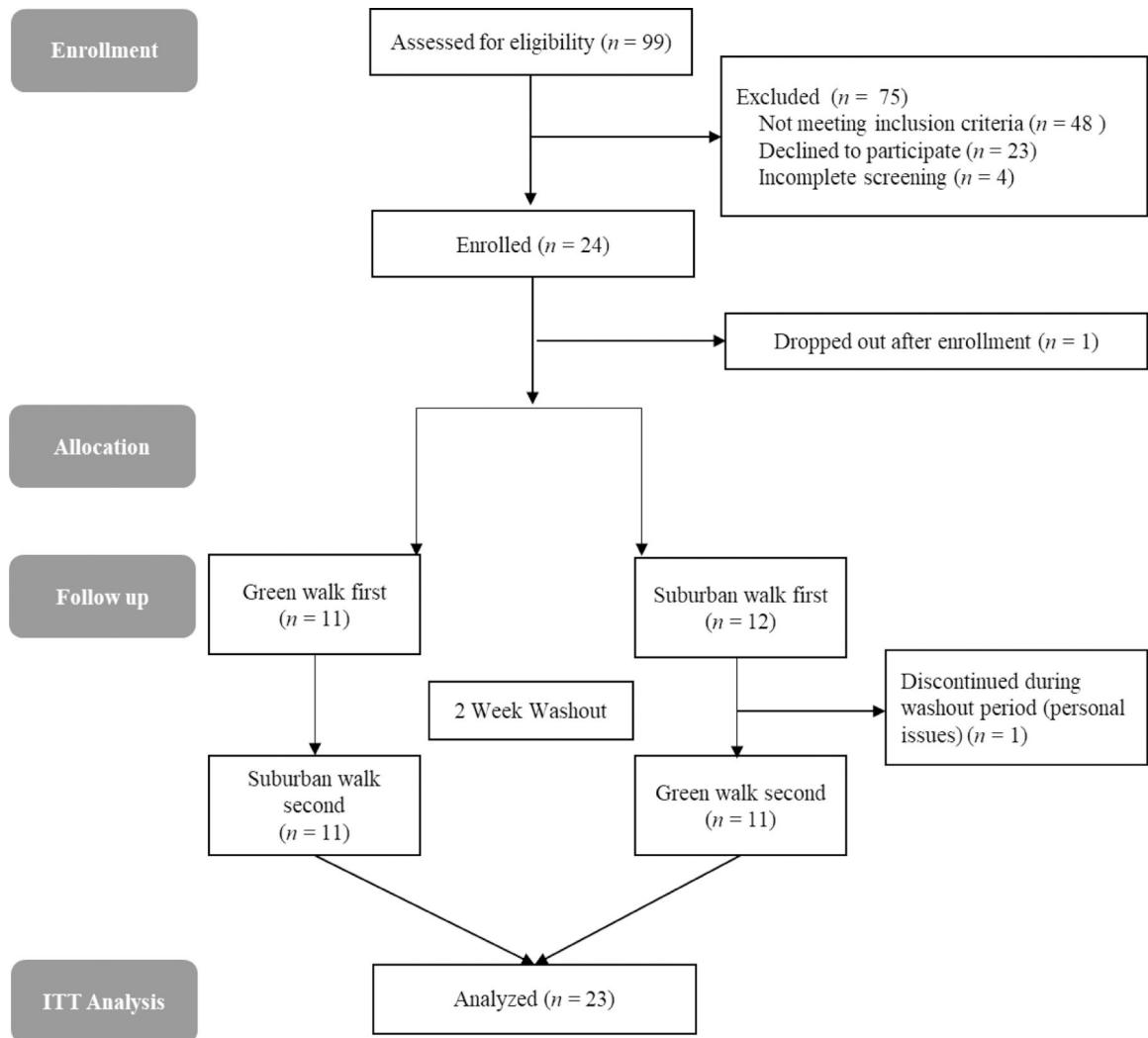


Fig. 2. CONSORT Flow Diagram modified for non-randomized crossover trial design. <<1.5-column fitting image>>

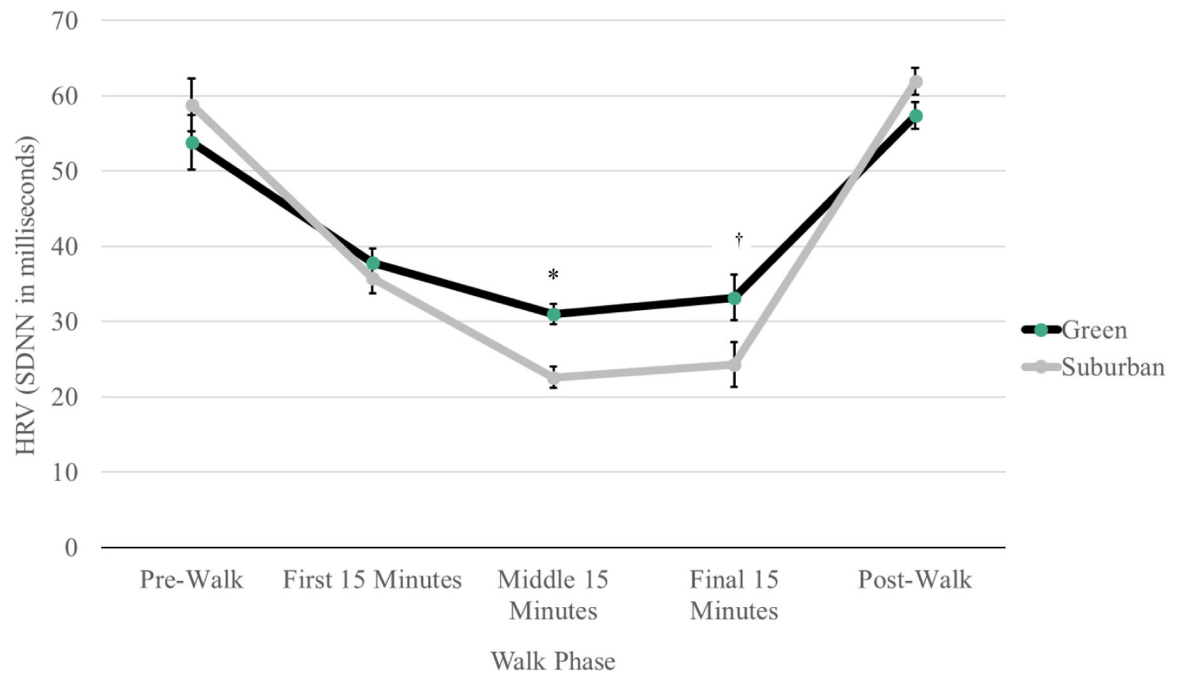


Fig. 3.

Line graph shows average heart rate variability (ms) change across walk phases by green and suburban conditions ($n = 23$). *<< 1.5-column fitting image >>*

Note. Data are presented as mean \pm SE. Between-condition contrasts, mean (95% CI): pre-walk: -5.0 ($-9.9, -0.08$); first 15 min: 2.1 ($-2.6, 6.8$); second 15 min: 8.4 ($6.0, 10.9$)*; final 15 min: 8.9 ($1.2, 16.6$)[†]; post-walk: -4.5 ($-8.0, -1.1$).

Table 1.

Selected baseline demographics and health characteristics of participants included in the analytical sample ($n = 23$).

<i>Characteristic</i>	
Age, mean \pm SD, y	49.7 \pm 6.5
Female, n (%)	19 (83)
Education, n (%)	
College/Some college	17 (74)
Graduate level	6 (26)
Household Income, n (%)	
<49,999	4 (17)
50,000–99,999	8 (35)
100,000 or more	9 (39)
Prefer not to answer	2 (9)
Exercise, mean \pm SD, days/week	1.7 \pm 0.6
Body mass index, n (%), kg/m ²	
Normal (18.5–24.99)	8 (33)
Overweight (25–29.99)	6 (25)
Obese (\geq 30.0)	10 (42)
Body fat percentage, mean \pm SD	38.4 \pm 10.1
Resting blood pressure, mean \pm SD	
Systolic (mmHg)	124.7 \pm 14.0
Diastolic (mmHg)	79.5 \pm 11.3
Resting HRV, mean \pm SD, ms	45.5 \pm 18.4
Resting HR, mean \pm SD, beats per minute	70.3 \pm 16.4

Note. kg/m², kilograms/meter squared; mmHg, millimeters of mercury; HRV, heart rate variability; ms, milliseconds; HR, heart rate.

Table 2.

Pre- and post-walk mean systolic and diastolic blood pressure (mmHg) by green and suburban conditions ($n = 23$).

	Green		Suburban	
	Pre-walk	Post-walk	Pre-walk	Post-walk
Blood pressure	mean \pm SE		mean \pm SE	
Systolic	120.8 \pm 3.2	117.3 \pm 2.9	120.2 \pm 3.2	117.4 \pm 2.9
Diastolic	74.1 \pm 2.1	75.1 \pm 2.3	74.6 \pm 2.1	74.9 \pm 2.3

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