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Acute effects of visits to urban green environments on cardiovascular physiology in women: A field experiment

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ABSTRACT

Background: Epidemiological studies have reported positive associations between the amount of green space in the living environment and mental and cardiovascular human health. In a search for effect mechanisms, field studies have found short-term visits to green environments to be associated with psychological stress relief. Less evidence is available on the effect of visits on cardiovascular physiology.
Objectives: To evaluate whether visits to urban green environments, in comparison to visits to a built-up environment, lead to beneficial short-term changes in indicators of cardiovascular health.
Methods: Thirty-six adult female volunteers visited three different types of urban environments: an urban forest, an urban park, and a built-up city centre, in Helsinki, Finland. The visits consisted of 15 min of sedentary viewing, and 30 min of walking. During the visits, blood pressure and heart rate were measured, and electrocardiogram recorded for the determination of indicators of heart rate variability. In addition, levels of respirable ambient particles and environmental noise were monitored.
Results: Visits to the green environments were associated with lower blood pressure (viewing period only), lower heart rate, and higher indices of heart rate variability [standard deviation of normal-to-normal intervals (SDNN), high frequency power] than visits to the city centre. In the green environments, heart rate decreased and SDNN increased during the visit. Associations between environment and indicators of cardiovascular health weakened slightly after inclusion of particulate air pollution and noise in the models.
Conclusions: Visits to urban green environments are associated with beneficial short-term changes in cardiovascular risk factors. This can be explained by psychological stress relief with contribution from reduced air pollution and noise exposure during the visits. Future research should evaluate the amount of exposure to green environments needed for longer-term benefits for cardiovascular health.

1. Introduction

Urbanization is a global phenomenon which shows no signs of slowing down. Consequently, the quality of urban environment has become increasingly important for human health. Urban green environments, such as parks and urban forests, are elements of environment which many intuitively consider healthy. Although the evidence cannot yet be claimed sufficient and there are issues related to potential exposure misclassification and confounding, many epidemiological studies indeed have reported that persons living in greener environments have better mental and cardiovascular health than persons living in more built-up environments (Gascon et al., 2016, 2015; Maas et al., 2009b).

Several mechanisms have been proposed by which living close to green areas may affect positively health: for example, beneficial effects may be partly due to reduced exposure to traffic-related air pollution and noise. Increased amount of green space in a residential area typically implies less traffic. This reduces exposure to air pollution and

Abbreviations: BP, blood pressure; HF, high frequency power; HRV, heart rate variability; LAeq, A-weighted equivalent continuous sound pressure level; PM_{10}, respirable particles, particles with aerodynamic diameter < 10 µm; SDNN, standard deviation of the normal inter-beat intervals; RMSSD, square root of the mean of the sum of the squares of differences between adjacent normal-to-normal intervals

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noise both indoors at home and outdoors near home. In addition, vegetation may decrease pollutant levels locally by affecting dispersion and removal (Jang et al., 2015; Tyrväinen et al., 2005). Both long-term and short-term exposures to traffic-related air pollution have been associated with deteriorations in cardiovascular health (Brook et al., 2010). Traffic noise in turn seems to be associated with cardiovascular health independently of air pollution (Vienneau et al., 2015), and it may be associated also with mental health (Floud et al., 2011; Leslie and Cerin, 2008; Sygna et al., 2014), although there are surprisingly few studies on the topic.

Other proposed mechanisms require the use of green environments. For example, green areas offer opportunities for physical activity which is an established protective life-style factor against cardiovascular disease and depression (Conn, 2010; World Health Organisation, 2010). Some studies have indeed reported that living in proximity to green areas increases the likelihood of frequent exercise (e.g. Gong et al., 2014; Richardson et al., 2013). However, many other have not found evidence of an association between supply of green areas and level of physical activity (e.g. Hillsdon et al., 2006; Ord et al., 2013). Green areas have also been suggested to enhance social interactions (Maas et al., 2009a; de Vries et al., 2013), which may or may not involve exercise, but the health relevance of this has not yet been widely studied (Hartig et al., 2014; Ruijsbroek et al., 2017).

Last but not least, it has been suggested that, because of intrinsic qualities of natural elements, green areas have also more direct positive effects on wellbeing and further health. These effects could be explained by restoration of attention as a result of escaping daily routines and constant need of concentration (Kaplan 1995), or by innate triggering of positive emotions (Ulrich 1983). There is an increasing amount of experimental studies, as reviewed by Bowler et al. (2010), reporting that short visits to green environments such as parks, urban woodlands, and forests improve mood and attention, and enhance psychological stress recovery. We have recently reported visits to urban green environments to be associated with increased feelings of restoration, vitality, and positive mood (Tyrväinen et al., 2014)

Evidence on the importance of good mental health for physical health has increased especially for cardiovascular diseases over the last few decades: for example chronic depression, anxiety, and working stress have been associated with increased cardiovascular morbidity (Gan et al., 2014; Kivimäki et al., 2006; Pietilä et al., 2015; Sparrenberger et al., 2009). A plausible effect mechanism has been provided by studies reporting acute psychosocial stress, mental effort, and worry to be associated with rapid changes in the levels of cardiovascular risks factors such as blood pressure, heart rate, and heart rate variability (HRV), a measure of autonomic nervous control of heart (e.g. Peters et al., 1998; Pieper et al., 2007). Noteworthy, short-term exposure to air pollution, such as experienced during commuting in a city centre with busy traffic, has been found to be associated with the same risk factors (e.g. Kubesch et al., 2015, Lanki et al., 2006; Sarnat et al., 2014).

Based on the previously reported associations between mental state and cardiovascular physiology, it can be hypothesized that even short visits to green environments may lead to positive changes in cardiovascular risk factors as a result of stress recovery. An increasing number of studies in Europe and US (Gidlow et al., 2016; Grazuleviciene et al., 2015; Hartig et al., 2003, 1991; Sonntag-Öström et al., 2014; Triguero-Mas et al., 2017), and mostly smaller scale studies in Japan (Lee et al., 2014, 2011; Li et al., 2011; Park et al., 2010; Song et al., 2014), have evaluated effects of visits to green areas, in comparison to visits to built-up urban areas, on blood pressure, heart rate or HRV. Several of the studies have reported positive effects, most often for HRV, but drawing solid conclusions has been hampered by the heterogeneity of study designs and results (Bowler et al., 2010). Further, the effect of reduction in air pollution and noise exposure during visits to green environments has been taken into account in only one previous study (Triguero-Mas et al., 2017), where further analyses were hampered by the lack of overall effect of green areas on cardiovascular physiology. Noteworthy, some studies suggest that a mere visual exposure to green environment, in a form of a picture or video, is enough to trigger positive physiological changes (Brown et al., 2013; Lauman et al., 2003).

It can be further hypothesized that psychophysiological responses to visits to green areas are dependent on the quality of the area. For example high biodiversity, natural state, solitude, and tranquility are attributes that may enhance experience of nature during visit and improve restoration (Korpela and Staats, 2014; Voigt et al., 2014). These characteristics are more commonly found in larger forested areas than small urban parks. Other determinants of effects and usage of green areas include e.g. walkability, safety, and facilities (Hartig et al., 2014). There is little information on the modifying effect of the quality of green environments on mental or cardiovascular health (Marselle et al., 2014; Pope et al., 2015).

In order to test the hypotheses above, acute effects of short visits to two types of green urban environments on cardiovascular physiology are estimated in this field study, and compared to the effects of visits to a built-up urban environment. The present study includes adult employed volunteers in contrast to earlier studies which have often relied on student samples. A rare feature of the study is the inclusion of traffic-related air pollution and noise exposures in the analyses.

2. Methods

2.1. Study design

The study took place in Helsinki, the capital of Finland, where volunteers visited once three different types of environments, named here as: urban forest, urban park, and (built-up) city centre. The urban forest (Keskuspuisto) is the largest forested area in Helsinki with a total size of 1000 ha. It is 10 km in length, and consists of 60–100 year old mixed and conifer forests. The urban park (Alppipuisto) is one of the oldest urban parks in Helsinki covering together with a neighboring park 20 ha. It is well-designed with flower beds, water element, old park trees, and facilities such as benches and a performance stage for live music. The environment representing a city centre was close to a main street (Mannerheimintie) and a shopping centre – only single urban trees were found on the area. Photos of the study environments can be found in a previous publication (Tyrväinen et al., 2014).

We followed to some extent the protocol used in field experiments conducted in Japan (Lee et al., 2014; Tsunetsugu et al., 2013). Study participants visited the environments in partly changing groups of four people in a random order; no more than one environment per week. Participants were asked not to communicate with each other during the visits. Each visit consisted of a 15-min period of sitting and viewing the environment, and a 30-min period of unhurried walking in the environment. During the walking period, study participants followed a researcher who kept a steady pace (aiming at 4 km/h) on a prescribed route (approximately 2 km). Another researcher followed the participants, and carried a backpack which contained instruments for monitoring of air pollution, environmental noise, and ambient temperature.

All experiments started at 3 p.m., i.e. after a normal working day for most of the participants. Participants got an SMS reminder in the morning of each experimental day. On each visit, participants first arrived at an office, where blood pressure and electrocardiogram (ECG) monitors were installed by researchers. At the office, each participant also filled in a questionnaire on current health condition, and ate a sandwich and drank a juice in order to standardize energy level. Before leaving the office, participants rinsed their mouths with water to prepare for cortisol measurements. Participants were brought to the study environment from the office in a van (20–30 min driving time).

Blood pressure was measured first at the office in order to test the instruments, and then 3 times during the experiment: in the van after arrival to the study environment (control value), after the viewing period while still sitting, and after the walking period in the van. ECG monitors were running throughout the experiment. With the exception of the office environment, blood pressure measurements were always followed by collection of saliva samples and filling in psychological questionnaires. Saliva samples were used for the determination of cortisol, a hormone indicator of stress. Questionnaires were used to evaluate changes in e.g. restoration, vitality, and mood during the visits. Results of the cortisol measurements and psychological measures can be found in a paper by Tyrväinen et al. (2014). The earlier paper included additional participants for which no ECG, air pollution, and noise data was available.

Data included in the current paper was collected during two periods: first group of participants visited the three environments in autumn 2011, and the second group in autumn 2012 (after additional funding was obtained). The visits took place between mid-August and mid-September, during which period temperature is still relatively high and the nature green in Helsinki.

2.2. Study population

Study participants, aged 30–60 years, were recruited by contacting personal managers in some governmental and municipal organizations, who then forwarded an invitation letter via intranet or e-mail lists (volunteers at national research institutes were restricted to those not involved with forest and/or health studies of any kind). An invitation for staff was also published in the monthly bulletin of the University of Helsinki. Finally, in 2012 invitation letters were also delivered to households located nearby the office used as the meeting point for the experimental visits. The invitation included a short description of the study, and instructions on how to sign up for the study. Those expressing interest received more information on the study by post or phone, including description of the study procedure, risks associated with the study, and confidentiality issues. They were also asked to fill in a baseline questionnaire that included questions on e.g. working life, diet, health and medication use, nature orientedness, noise sensitivity, and the use of green areas in everyday life.

Exclusion criteria for the study were: smoking, cardiac pacemaker, hearing aid, doctor-diagnosed myocardial infarction, coronary heart disease, congestive heart failure, stroke, and chronic obstructive pulmonary disease. In addition, persons without medication for asthma, blood pressure or diabetes were preferred. Study participants were asked to avoid alcohol and tobacco use as well as heavy physical activity before the experiment.

The Research Ethics Committee of the Northern Savo Hospital District approved the study. All study participants gave a written consent for the study during their first visit.

2.3. Medical data

Blood pressure (BP) and heart rate were measured with oscillometric blood pressure monitors (Model 90217, Spacelabs Healthcare, Snoqualmie, Washington, USA). Before leaving to an experimental site, a cuff was wrapped around the left arm of the participant. An air hose connected the cuff to the blood pressure monitor, which was carried in a small case attached to a belt or shoulder strap.

Blood pressure and heart rate were measured in sitting position from the left arm resting on lap. Before each measurement, study participants sat still for at least 3 min. At a researcher's request they then pushed a button starting the measurement. A second measurement was started 60 s after the first one was finished. In the analyses, the average of the two measurements was used.

Electrocardiograms were recorded with Holter-monitors (Medilog AR12 Plus, Schiller AG, Baar, Switzerland). Seven electrodes, attached to the chest of a participant, were used to record ECG in 3 channels with a sampling frequency of 125 Hz; measurements were started at the office. Participants carried the monitor in a small case attached to a belt or shoulder strap. Indicators of heart rate variability were calculated with the Darwin Software (Schiller AG) for the control, viewing, and total (viewing + walking) periods.

Heart rate variability, the change in the time intervals between adjacent heartbeats, is a measure of the autonomic nervous control of heart rate. We used two indicators of HRV based on time-domain analyses: the standard deviation of the normal inter-beat intervals (SDNN), and the square root of the mean of the sum of the squares of differences between adjacent normal-to-normal intervals (RMSSD). In addition, high frequency power (HF) was estimated based on frequency domain analyses. SDNN reflects all factors that contribute to HRV, whereas RMSSD reflects high-frequency variation in HRV and is used to estimate vagally mediated changes in HRV. HF is also used to evaluate vagal activity, but is more influenced by the respiratory cycle (Shaffer et al., 2014).

2.4. Environmental data

In the data analyses, concentration of respirable particles (PM_{10}; aerodynamic diameter < 10 μm) during the visit was used as an indicator of exposure to particulate air pollution. In addition, black carbon and particle number concentration were monitored. In urban areas, spatial distribution of PM_{10} is typically driven by emissions of road traffic, including road dust. It was measured with a photometer (DustTrak DRX 5833, TSI Inc., Shoreview, Minnesota, USA) that was equipped with a PM_{10} impactor; time resolution was 5 s. The flow rate was calibrated to 3 l/min with a BIOS Defender calibrator (Brandt Instruments Inc., Prairieville, California, USA). Black carbon was monitored with a microaethalometer (Magee Scientific AE52, Magee Scientific Corp., Berkeley, California, USA) and particle number concentration with a condensation particle counter (TSI P-Trak, TSI Inc., Shoreview, Minnesota, USA).

Environmental noise levels were measured with class II Larson Davis Spark 706 noise dosimeters (PCB Piezotronics Inc., Depew, New York, USA) together with Larson Davis MPR001 integrated microphone/preamplifiers. A-weighted equivalent continuous sound pressure levels (LAeq) during the visits were used in the data analyses. Ambient temperature and humidity were recorded with dataloggers (Escort iLog EI-HS-D-32-L, Cryopak, Edison, New Jersey, USA) attached to the exterior of the backpack (containing air pollution monitors) carried by a researcher.

Researchers assessed the weather before each viewing and walking period, and after the walking period. Categories used to record the weather were: sunny, partly cloudy, cloudy, drizzle. Experiment was cancelled if there was heavy rain.

2.5. Data analyses

In order to compare the effects of visits in different environments on indicators of cardiovascular health, mixed models were built using SAS software (SAS Institute Inc. Cary, NC, USA). Models included before and after visit values of blood pressure/heart rate for each subject in each environment. HRV was measured continuously, and therefore averages of before visit and during visit values were used in the models. Study participants were treated as repeating factors in the models in order to take into account longer-term differences between subjects in the outcome variables, as well as environment-independent daily variation within subjects (i.e. study participants served as their own controls). The observations within a subject were assumed to be equally correlated. This is the same kind of structure that arises in a normal linear model with random intercepts (i.e., random subjects). It acknowledges that correlations exist within a subject, but it assumes that the correlations are constant over time.

The basic model included ambient temperature and weather category as confounders. In additional models, also PM_{10} and noise levels during the visit were included in order to evaluate whether (potentially) lower air pollution and noise levels in green areas contribute to the effect of visits, and subsequently whether the quality of the green area is of importance.

It was anticipated that physical strain of walking, even in a slow speed, might mask some of the effects of environment on cardiovascular physiology. Therefore, the effect of viewing only was evaluated in separate analyses.

In a complementary approach, effects of visits on indicators of cardiovascular health were evaluated by calculating for each participant in each environment the difference between outcome values after visit (or during visit for HRV) and before visit. T-test was used to evaluate statistical significance of the difference. A positive value corresponded to an increase during the visit, which was interpreted as a harmful change in blood pressure and heart rate, but beneficial concerning the indices of HRV.

3. Results

Physiological measurements were conducted on 40 volunteers. However, 2 volunteers visited only one environment, and were therefore excluded from further analyses. Because there were only 2 males, the data was further restricted to include only females, leaving 36 persons in the final data set.

Based on the baseline questionnaire, average age of the study participants was 46 years (standard deviation 8.7 years). All participants were employed, and 14 (39%) of them considered their work at least fairly stressful. Twenty-five persons (69%) visited green environments at least 4 times a week in everyday life, and thirty-two (89%) at least twice a week (data not shown).

Mean values and standard deviations of the outcome and main environmental variables during different experimental periods are presented in Table 1. Compared to the sedentary control and viewing periods, SDNN was much higher during the walking period in all environments. There was a clear trend in PM_{10} and noise, the levels being the highest in city centre and lowest in urban forest. In the further analyses on the physiological effects of the short visits, each study participant was assigned an estimate of exposure to PM_{10} and noise based on the measurements. These estimates differed statistically significantly ($p < 0.05$) between the three environments. However, when differences between the environments were evaluated based on one measurement per *group-visit*, the differences did not reach statistical significance for PM_{10} because of fewer observations. Even with this approach, noise levels during sitting differed statistically significantly from the levels recorded during the whole period.

Similar to PM_{10}, black carbon and particle number concentrations were the highest in city centre. Average concentration of black carbon in city centre, urban park, and urban forest was 2.19, 0.60, and 0.46 $\mu g/m^3$, respectively. Respective levels of particle number concentration were 8700, 3500, and 2600 particles/cm^3.

High correlations were observed between systolic and diastolic blood pressure (positive correlation), heart rate and indices of HRV (negative), and different indices of HRV (positive) (Suppl. Table 1). PM_{10} and noise levels were positively correlated, especially in urban forest.

No differences in blood pressure were observed between the green environments and city centre when the effect of visit was evaluated based on total experimental period, i.e. integrating the effect of viewing and walking periods (Table 2). Visits to the green environments were associated with lower heart rate and higher HF than visits to city centre, effect estimates were slightly higher for urban forest compared to urban park. SDNN was significantly higher in urban forest, but not park, compared to the city centre. Effect estimates for RMSSD were positive for green areas, but not statistically significant.

PM_{10} was statistically significantly associated with RMSSD, and borderline significantly (i.e. $0.05 \leq$ p-value < 0.1) with SDNN; both associations were negative (Table 2). Inclusion of PM_{10} in the models decreased effect estimates of green areas for SDNN. Environmental noise was negatively associated with HF, for SDNN and RMSS the association was borderline significant. After inclusion of noise in the models, the associations of environment with SDNN and HF were weaker but still apparent.

Sitting and viewing the landscape was associated with lower systolic blood pressure in urban forest than in city centre; the difference between urban park and city centre was smaller and only borderline significant (Table 3). No similar difference was observed for diastolic blood pressure. Visits in the green environments, especially urban forest, were associated with lower heart rate than visits in city centre. Visits to urban forest, but not urban park, were associated with higher SDNN than visits to city centre. RMSSD and HF were both higher in the green environments than in city centre.

PM_{10} was positively associated with systolic blood pressure, and heart rate (statistically borderline significantly), and negatively with RMSSD (borderline significantly) during the viewing period (Table 3). For these outcomes, inclusion of PM_{10} in the models substantially decreased effect estimates for the green areas. Environmental noise was statistically significantly associated with decreased SDNN, and borderline significantly with decreased diastolic blood pressure and

Table 1
Descriptive statistics for physiological and environmental variables.

		Before viewing			After/during viewing			After/during walking		
		City	Park	Forest	City	Park	Forest	City	Park	Forest
BP systolic [mm Hg]	Mean	120.6	119.9	119.2	124.1	120.8	119.9	119.0	122.1	121.6
	SD	14.0	12.7	13.5	16.7	13.5	16.0	13.5	12.4	13.1
BP diastolic [mm Hg]	Mean	78.1	76.9	77.3	78.7	78.7	77.2	77.6	79.5	79.3
	SD	9.9	8.9	8.5	9.7	9.3	9.2	8.9	8.0	9.4
Heart rate [bpm]	Mean	72.3	72.0	71.4	71.3	67.8	66.7	72.1	67.5	68.7
	SD	10.3	9.4	10.9	11.1	9.4	10.4	11.6	9.0	11.9
SDNN [ms]	Mean	50.4	48.3	53.6	54.4	60.3	67.0	100.7	107.3	118.9
	SD	16.9	15.0	19.9	20.1	25.6	29.0	28.8	34.3	32.9
RMSSD [ms]	Mean	29.4	29.2	29.3	31.2	38.9	38.1	24.1	28.6	27.4
	SD	14.7	15.4	17.4	15.9	24.1	20.3	10.5	15.7	13.0
HF [ms^2]	Mean	58.6	60.8	70.0	79.9	147.9	138.7	41.3	73.4	70.0
	SD	55.4	60.2	84.3	78.7	176.0	140.9	37.8	86.1	66.2
PM_{10} [$\mu g/m^3$]	Mean	17.8	14.4	14.6	20.8	14.3	12.8	20.3	13.4	11.8
	SD	9.9	8.4	7.3	9.3	9.3	5.4	9.1	8.5	4.2
LAeq [dBA]	Mean	63.4	63.6	64.6	63.3	59.2	57.9	66.4	62.5	58.6
	SD	1.0	2.5	1.0	1.2	1.4	3.1	1.2	1.3	2.6
Temperature [^oC]	Mean	24.1	23.9	23.7	24.8	24.7	22.3	23.6	23.5	19.9
	SD	1.0	1.1	1.1	2.5	2.9	2.5	2.6	3.1	2.3

Table 2
Effects of visits to urban green environments on cardiovascular physiology – total (viewing and walking) experimental period. City centre used as a reference environment.

		Basic model*		Adjusted for air pollution†			Adjusted for noise§		
		Park	Forest	Park	Forest	PM10	Park	Forest	LAeq
BP systolic	Estimate	0.44	−0.60	0.31	−0.76	−0.15	0.03	−1.15	−0.88
	SE	1.23	1.30	1.31	1.43	0.54	1.32	1.45	1.02
	P-value	*0.723*	*0.648*	*0.812*	*0.598*	*0.785*	*0.984*	*0.432*	*0.394*
BP diastolic	Estimate	0.39	−0.21	0.37	−0.24	−0.03	0.02	−0.71	−0.79
	SE	0.80	0.84	0.85	0.93	0.36	0.86	0.94	0.66
	P-value	*0.624*	*0.801*	*0.665*	*0.795*	*0.941*	*0.980*	*0.451*	*0.235*
Heart rate	Estimate	**−2.46**	**−2.69**	**−2.23**	**−2.39**	0.29	**−2.16**	**−2.29**	0.64
	SE	**0.80**	**0.84**	**0.85**	**0.93**	0.36	**0.86**	**0.94**	0.66
	P-value	***0.003***	***0.002***	***0.011***	***0.012***	*0.430*	***0.014***	***0.018***	*0.333*
SDNN	Estimate	2.61	**10.8**	0.76	**8.68**	−2.34	0.48	**7.91**	−4.80
	SE	3.29	**3.50**	3.46	**3.71**	1.41	3.49	**3.84**	2.73
	P-value	*0.431*	***0.003***	*0.826*	***0.023***	*0.099*	*0.891*	***0.044***	*0.081*
RMSSD	Estimate	2.13	1.97	1.32	1.01	**−1.09**	1.40	0.98	−1.65
	SE	1.17	1.24	1.24	1.33	**0.55**	1.24	1.37	0.98
	P-value	*0.075*	*0.118*	*0.291*	*0.449*	***0.048***	*0.265*	*0.479*	*0.093*
HF	Estimate	**21.9**	**27.4**	**19.1**	**24.1**	−3.77	**15.9**	**19.2**	**−13.75**
	SE	**6.16**	**6.54**	**6.51**	**7.00**	2.84	**6.44**	**7.10**	**5.05**
	P-value	***0.001***	***< 0.001***	***0.005***	***0.001***	*0.187*	***0.017***	***0.009***	***0.007***

Statistically significant (p-value < 0.05) estimates in bold font.
* adjusted for weather and temperature.
† adjusted for weather, temperature and PM_{10}. Effect estimate for PM_{10} calculated for a 5 μg/m^3 increase in exposure.
§ adjusted for weather, temperature and LAeq. Effect estimate for noise calculated for a 5 dBA increase in exposure.

RMSSD. After inclusion of noise in the models, the effect estimates for urban forest decreased; however, there also emerged a borderline significant difference between urban forest and city centre for diastolic blood pressure.

Within-participant changes in the outcome variables during the visits are presented in Figs. 1–4 and Supplemental Table 2. Looking at the whole experimental period (Figs. 1 and 2, Supplemental table 2), diastolic blood pressure was observed to increase in the green environments; increased values were observed also for systolic blood pressure, but the changes were not statistically significant. Heart rate decreased significantly in the green environments. SDNN increased during visits in all environments, the most in urban forest, followed by urban park. RMSSD and HF decreased in city centre, but were not affected by visits to the green environments.

During the viewing period, systolic blood pressure increased in city centre, and diastolic blood pressure in urban park (borderline significant) (Figs. 3 and 4, Supplemental Table 2). Heart rate was decreased during viewing in all environments, especially in urban park and forest. SDNN, RMSSD, and HF were significantly increased in the green environments. In city centre, the increase was significant only for HF.

4. Discussion

In this field experiment, female volunteers visited three different types of urban environments: a built-up city centre, an urban park, and an urban forest. The visit consisted of a 15-min viewing period (in a sitting position) and a 30-min walking period. Visits to green

Table 3
Effects of visits to urban green environments on cardiovascular physiology – viewing period only. City centre used as a reference environment.

		Basic model*		Adjusted for air pollution†			Adjusted for noise§		
		Park	Forest	Park	Forest	PM_{10}	Park	Forest	LAeq
BP systolic	Estimate	−2.60	**−3.64**	−1.27	−2.24	**1.21**	−2.32	**−3.28**	0.96
	SE	1.39	**1.48**	1.50	1.60	**0.57**	1.44	**1.56**	1.30
	P-value	*0.066*	***0.017***	*0.400*	*0.166*	***0.034***	*0.110*	***0.039***	*0.458*
BP diastolic	Estimate	−0.25	−1.16	0.29	−0.59	0.49	−0.61	−1.64	−1.30
	SE	0.83	0.89	0.91	0.97	0.35	0.86	0.93	0.77
	P-value	*0.766*	*0.198*	*0.749*	*0.546*	*0.156*	*0.475*	*0.082*	*0.094*
Heart rate	Estimate	**−2.14**	**−2.91**	−1.56	**−2.32**	0.52	**−1.92**	**−2.62**	0.78
	SE	**0.73**	**0.78**	0.80	**0.85**	0.31	**0.75**	**0.82**	0.68
	P-value	***0.005***	***< 0.001***	*0.054*	***0.008***	*0.092*	***0.013***	***0.002***	*0.249*
SDNN	Estimate	0.85	**6.54**	−0.02	5.62	−0.88	−0.96	4.02	**−7.19**
	SE	2.70	**2.74**	2.91	2.97	1.10	2.70	2.80	**2.46**
	P-value	*0.754*	***0.020***	*0.995*	*0.063*	*0.425*	*0.723*	*0.157*	***0.004***
RMSSD	Estimate	**4.26**	**4.51**	2.98	3.21	−1.28	**3.65**	**3.66**	−2.46
	SE	**1.57**	**1.60**	1.71	1.74	0.68	**1.61**	**1.67**	1.47
	P-value	***0.009***	***0.006***	*0.085*	*0.069*	*0.062*	***0.027***	***0.032***	*0.096*
HF	Estimate	**48.3**	**52.3**	**41.7**	**45.4**	−6.68	**43.8**	**46.1**	−17.70
	SE	**12.5**	**12.7**	**13.5**	**13.7**	5.20	**12.7**	**13.2**	11.61
	P-value	***< 0.001***	***< 0.001***	***0.003***	***0.002***	*0.200*	***0.001***	***0.001***	*0.129*

Statistically significant (p-value < 0.05) estimates in bold font.
* adjusted for weather and temperature.
† adjusted for weather, temperature and PM_{10}. Effect estimate for PM_{10} calculated for a 5 μg/m^3 increase in exposure.
§ adjusted for weather, temperature and LAeq. Effect estimate for noise calculated for a 5 dBA increase in exposure.

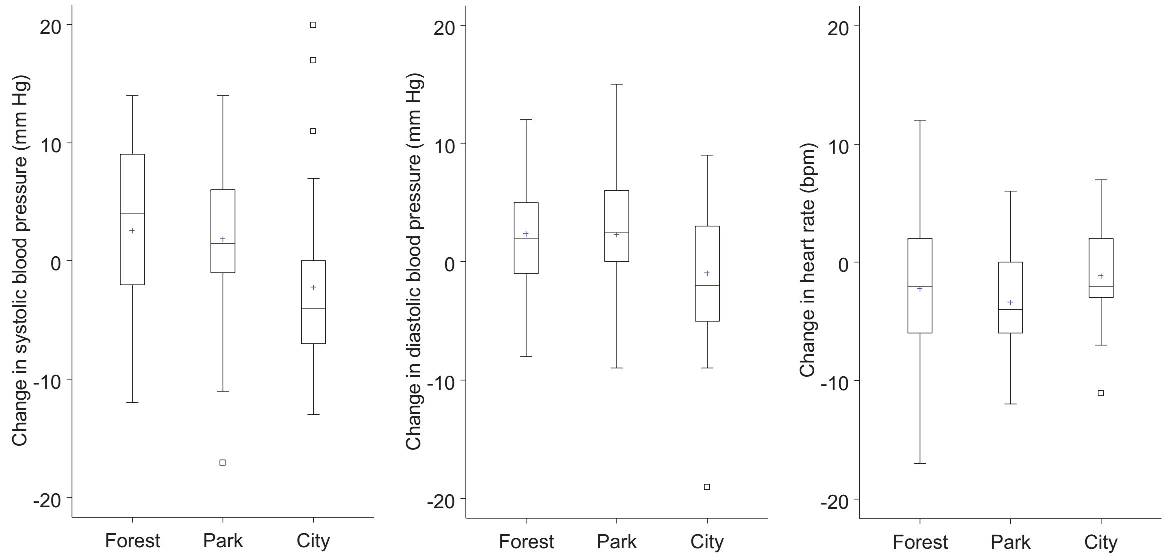
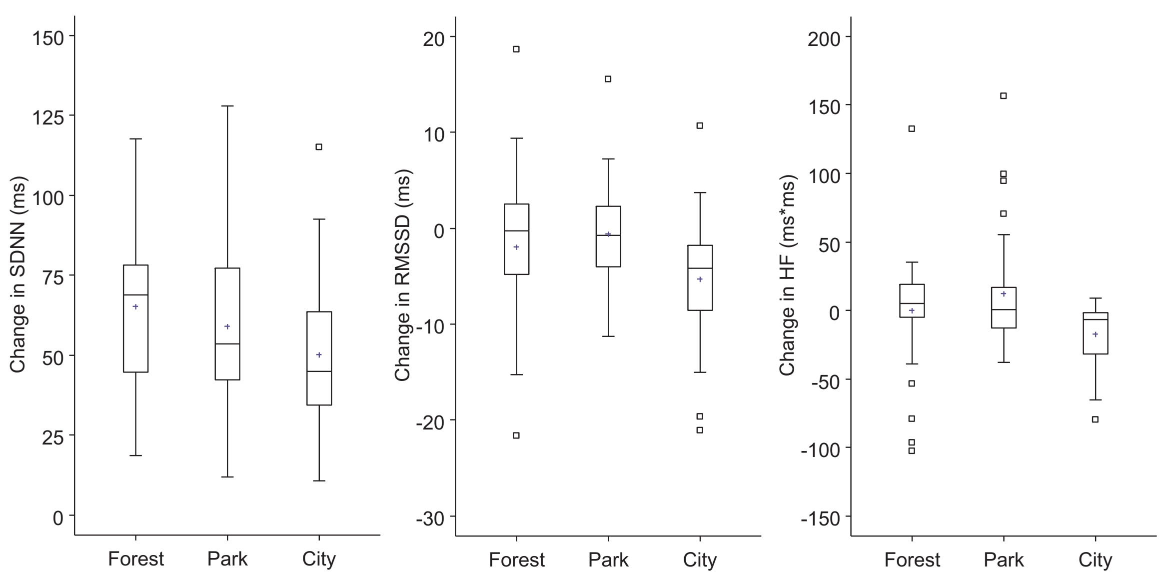


Fig. 1. Box-plots of within-person changes (after - before visit) in blood pressure and heart rate during the visits (total experimental period). Whiskers indicate maximum (and minimum) observations below upper (lower) fence set at 1.5 × interquartile range above (below) 75th (25th) percentile.

environments were associated with lower heart rate and higher heart rate variability (SDNN and HF) than visits to the city centre. In green environments, heart rate decreased and SDNN increased during the visit. Systolic blood pressure and RMSSD were dependent on the type of environment only in the analyses restricted to the viewing period. Particulate air pollution was associated with increased systolic blood pressure and decreased RMSSD, and environmental noise with decreased indicators of HRV. Associations between environment and indicators of cardiovascular health slightly weakened after the inclusion of air pollution and noise in the models. Mostly minor differences in effects were observed between the urban park and forest.

Study visits to urban environments were intended to reflect real-life visits outdoors to relax after work in that they took place after a normal working day for most of the volunteers, were relatively brief, and did not include strenuous exercise. Visits to green areas were associated with decreased heart rate and increased SDNN and HF, i.e. beneficial changes in cardiovascular physiology, compared to visits to the city centre. Green environments have been associated with lower heart rate and/or higher HF also in several Japanese studies (e.g. Lee et al., 2014; Song et al., 2014; Tsunetsugu et al., 2007). Taken together, the results suggest that related to cardiovascular health it is advantageous to relax and exercise in urban nature areas rather than in built-up city centres. However, some recent European studies have not found associations between green areas and HRV (Triguero-Mas et al., 2017; Gidlow et al., 2016), and results on heart rate have been mixed (Sonntag-Öström et al., 2014; Triguero-Mas et al., 2017).

Significantly lower particulate air pollution and noise levels were observed in the green areas than in the built-up city centre. Exposure to PM_{10} was associated with increased systolic blood pressure and decreased RMSSD, i.e. with harmful changes. The latter result is in line



SDNN = standard deviation of normal-to-normal intervals

RMSSD = square root of the mean of the sum of the squares of differences between adjacent normal-to-normal intervals

HF = high frequency power

Fig. 2. Box-plots of within-person changes (during –before visit) in heart rate variability during the visits (total experimental period). Whiskers indicate maximum (and minimum) observations below upper (lower) fence set at 1.5 × interquartile range above (below) 75th (25th) percentile.

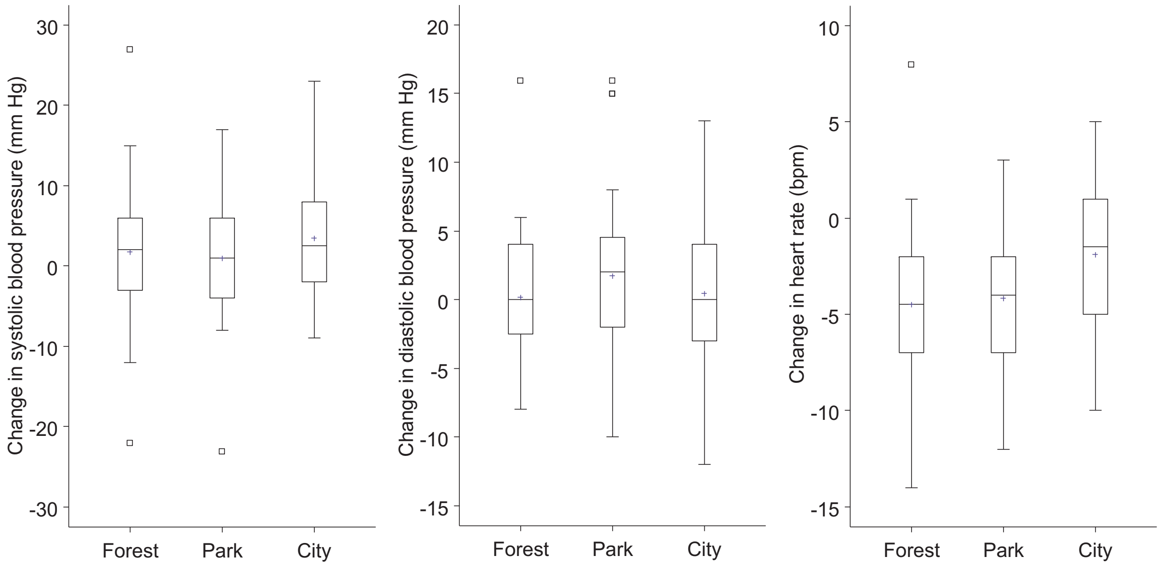
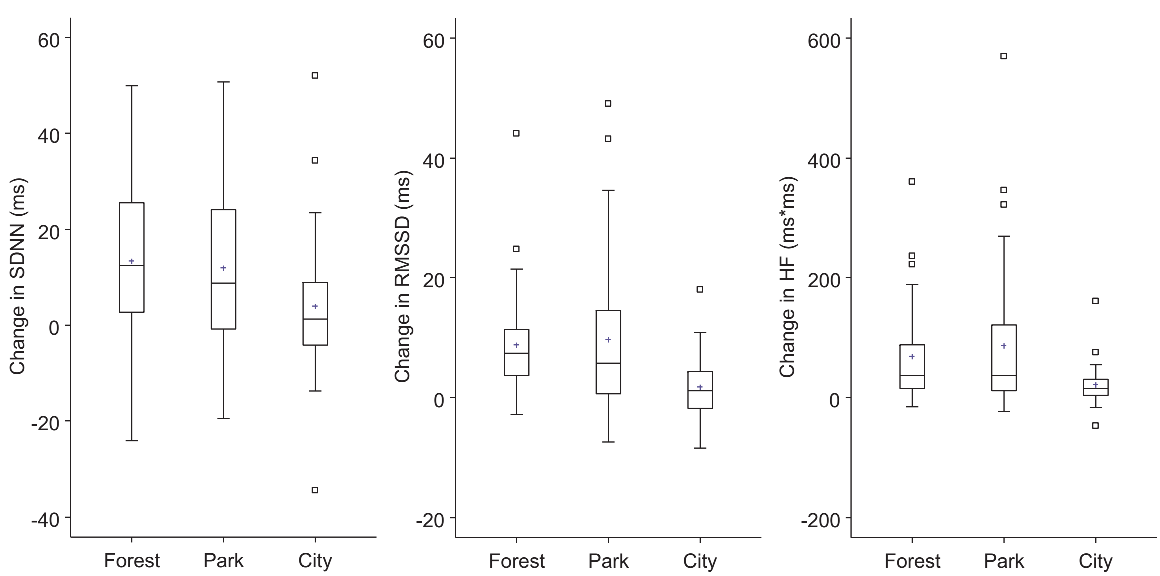


Fig. 3. Box-plots of within-person changes (after - before visit) in blood pressure and heart rate during the viewing period. Whiskers indicate maximum (and minimum) observations below upper (lower) fence set at 1.5 × interquartile range above (below) 75th (25th) percentile.

with previous studies on cardiovascular effects of brief air pollution exposures (Kubesch et al., 2015; Lanki et al., 2008; Sarnat et al., 2014). Further, negative associations were observed between noise exposure and all HRV indicators. This is not surprising because noise is a stress factor, and stress is known to be associated with increased sympathetic nervous activity (Pieper et al., 2007). All in all, the current results indicate that lower air pollution and noise levels contribute to cardiovascular health benefits of visits to green areas. It should be noted that air pollution and noise levels are relatively low in Helsinki. Therefore, the contribution of reduced pollutant exposure to cardiovascular benefits of 'green visits' may be higher in cities where the contrasts in exposure between city centres and urban green areas are higher. Importantly, differences in the effects between the three environments mostly remained even after the inclusion of air pollution and noise in the models. This suggests that other characteristics of green areas such as presence of natural elements are most important for the cardiovascular benefits.

Physical activity level affects blood pressure, heart rate and heart rate variability. It was anticipated that physical strain during walking, even at a relaxed speed, could mask underlying differences between environments, or create artificial differences because of the difficulty of adjusting physical strain exactly the same in all environments (due to more rough terrain in the woods, compulsory stops because of traffic lights in the city centre etc.). Therefore, results were also calculated separately for the viewing period, during which volunteers were sedentary. These results confirmed the associations observed during the whole experimental period. In addition, some new associations emerged: viewing the green sceneries was associated with lower



SDNN = standard deviation of normal-to-normal intervals

RMSSD = square root of the mean of the sum of the squares of differences between adjacent normal-to-normal intervals

HF = high frequency power

Fig. 4. Box-plots of within-person changes (during –before visit) in heart rate variability during the viewing period. Whiskers indicate maximum (and minimum) observations below upper (lower) fence set at 1.5 × interquartile range above (below) 75th (25th) percentile.

systolic blood pressure and higher RMSSD compared to viewing the city centre.

For blood pressure, results have been heterogeneous in previous studies. Several studies have not found, in contrast to the hypothesis, lower levels of blood pressure in green environments than in more built-up environments (Gidlow et al., 2016; Hartig et al., 2003; Lee et al., 2014; Triguero-Mas et al., 2017), whereas others have reported lower levels of diastolic but not systolic blood pressure (Park et al., 2009; Sonntag-Öström et al., 2014; Tsunetsugu et al., 2013, 2007). In a study conducted among coronary artery disease patients (Grazuleviciene et al., 2016), several visits were required before a difference in blood pressure was first time observed between visits to a park and a street environment.

Comparisons of the effects of visits to city centre and green environments provided some evidence on the cardiovascular health benefits of the latter. Another important question is, whether a visit to a green environment results in beneficial physiological changes. For diastolic blood pressure this seemed not to be the case as it increased rather than decreased during the visit. However, no such effect was evident when the analyses were restricted to the viewing period. Therefore, the increase may be related to physical activity rather than the environment. Heart rate and SDNN changed both during the viewing and total study period in green environments. For example, there was a 6% decrease in heart rate and a 25% increase in SDNN in urban forest during viewing. For RMSSD and HF, a beneficial change in green areas was observed only during the viewing period. The result suggests that even a short-term viewing of a natural environment has relaxing effects.

High resting heart rate and decreased HRV are established risk factors for cardiovascular diseases. More studies are yet needed to confirm the clinical relevance of the observed slight-to-moderate short-term changes in heart rate and HRV during the visits to the green environments. On a population level even small changes are relevant if the change is relatively permanent. Unfortunately, we were not able to follow the volunteers after the experiment. All in all, it is unclear how regular the visits to green environments have to be to lead to permanent changes in cardiovascular physiology. Related to this, it is not known whether our volunteers were to react more or less strongly to visits to green environments because they were regular users of green areas in their everyday life. Clearly, follow-up studies are needed also in other types of population groups (e.g. persons with mental health problems, unemployed persons), and both psychological and physiological factors affecting *long-term* physiological effects should be investigated. Visits to green areas may in real life include social interactions, but in this experimental setup most volunteers did not know each other beforehand, and they were asked not to communicate during the visits. An option for future studies is to enable natural social interactions in less supervised settings, which would also further reduce the effect of the presence of study personnel.

Short-term changes in mental state are known to be reflected in heart rate, blood pressure and HRV (e.g. Peters et al., 1998; Pieper et al., 2007). We have previously reported that urban green areas have stress relieving effects: rise of positive emotions, feelings of restoration and vitality (Tyrväinen et al., 2014). Current results indicate that psychological effects of visits to green areas further affect physiological processes. In the previous study, salivary cortisol level was not dependent on environment. It is not surprising that the effects are different for HRV and cortisol, as they are modulated via different systems, namely autonomic nervous system and hypothalamic-pituitary-adrenalin axis (Kajantie and Phillips, 2006). Both of them may affect cardiovascular reactivity (Brindle et al., 2014). Taken together, our studies suggest that heart rate and HRV may be better indicators of stress relief in short-term field experiments than cortisol. It should be noted that the study population in the current paper is a subset of the study population in the previous paper. The reason for a smaller study population was a practical one: ECG monitoring is strenuous for volunteers and laborious for the study personnel.

Mostly minor differences between the effects of visits to urban park and forest were observed in the current study or in our previous paper (Tyrväinen et al., 2014). Alppipuisto, the urban park, is well-designed with flower-beds, water elements and various facilities, and well-maintained. Keskuspuisto, the urban forest, covers a large area but is still affected by road and air traffic noise because of the elongated shape of the area. Study designs with more contrasts and environments, e.g. natural forests further away from cities and urban wastelands (i.e. not designed parks) used for recreational activities, can be used in future to identify characteristics that limit the health benefits of green environments.

There are differences in both cardiovascular physiology and physiological reactions to stress between women and men (Kajantie and Phillips, 2006, Koenig and Thayer, 2016; Pico-Alfonso et al., 2007), and the quality of environment may be more important for women (Beil and Hanes, 2013). Consequently the fact that the present study did not include both sexes can be seen as a main limitation. However, our results on heart rate and HRV were similar to the results of previous studies conducted among men (Lee et al., 2014; Song et al., 2014; Tsunetsugu et al., 2007), which supports generalizability of the observed effects. On the other hand, inclusion of adult women can be seen as strength of the study because previous studies have often included males, typically students (Bowler et al., 2010; Haluza et al., 2014). Lack of studies on physiological effects of outdoor nature among females was highlighted in a recent narrative review (Haluza et al., 2014).

Aging is a main risk factor for cardiovascular diseases, including atherosclerosis and hypertension. This is because aging is associated with e.g. remodeling of vascular walls, increased arterial stiffness, and decreased vagal function (Franklin, 2008; Lakatta, 2003, Meersman and Stein 2007). Age of the volunteers in this study ranged from 30 to 60. The substantial age range most likely has increased between-subject variation in physiological responses. It is worth noting that age is only one of many factors affecting cardiovascular functions, and therefore e.g. regular exercise can counteract effect of aging to some extent (Seals et al., 2009).

In conclusion, results of the study support the hypothesis that even short visits to green areas may lead to beneficial changes in cardiovascular risk factors. Further, environmental quality of green areas is of importance because air pollution and noise exposure counteract the benefits. In this respect, larger parks with some areas further away from busy traffic are recommendable. The current results are a reminder for city planners and public health community on the potential of urban green environments in promoting well-being and health.

Competing financial interests

The authors declare they have no actual or potential competing financial interests.

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Ethical approval

The Research Ethics Committee of the Northern Savo Hospital District has approved the study.

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Appendix A. Supplementary material

Supplementary data associated with this article can be found in the online version at http://dx.doi.org/10.1016/j.envres.2017.07.039.

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