Physical and mental health effects of repeated short walks in a blue space environment: a randomised crossover study

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Abstract

Introduction: Blue spaces may benefit mental health and promote physical activity, although the evidence is still scarce. And benefits on physical health are less consistent. The objective of this randomized crossover study was to assess psychological and cardiovascular responses to blue spaces' exposure.

Methods: A sample of 59 healthy adult office workers was randomly assigned to a different environment (i.e. blue space, urban space, and control site) on 4 days each week, for 3 weeks. For 20 minutes per day, they either walked along a blue or an urban space or rested at a control site. Before, during and/or after the exposure, we measured self-reported well-being and mood, blood pressure, and heart rate variability parameters. For well-being, we also assessed the duration of these potential effects over time (at least 4 hours after exposure).

Results: We found significantly improved well-being and mood responses immediately after walking in the blue space compared with walking in the urban space or when resting in the control site. Cardiovascular responses showed increased activity of the sympathetic nervous system, both during and after walking along the blue and urban spaces. However, cardiovascular responses measured after the walks, showed no statistically significant differences between the blue and the urban space environments.

Conclusions: Short walks in blue spaces can benefit both well-being and mood. However, we did not observe a positive effect of blue spaces for any of the cardiovascular outcomes assessed in this study.

Keywords: blue spaces; well-being; mood; cardiovascular health; physical activity.

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Highlights

- A randomised crossover study was done to evaluate health effects of blue spaces.
- We assessed repeated acute exposure to blue spaces, vs. urban spaces and a control.
- We found a positive effect for well-being/mood, but not for cardiovascular outcomes.
- Health effects of blue spaces on cardiovascular outcomes should be further explored.

1. Introduction

Blue spaces are considered "outdoor environments – either natural or manmade – that prominently feature water and are accessible to humans" (Grellier et al., 2017). A recent systematic review based on 35 studies reported that blue space exposure benefits mental health and well-being and improves physical activity levels, while the evidence for benefits on general health, obesity, cardiovascular and related outcomes was less consistent (Gascon et al., 2017). More recent studies have added to this evidence showing self-reported general and mental health (Garrett et al., 2019a; Hooyberg et al., 2020), physical activity, social interaction, and psychological benefits of blue spaces (de Bell et al., 2017), and the association between blue spaces exposure and health outcomes on older adults (Garrett et al., 2019b). But still, there are few studies on blue spaces health benefits and the methodological heterogeneity across them warrants further studies on this topic (Gascon et al., 2017).

Besides the physical environment, physical activity is also a key determinant of human's health (World Health Organization, 2018a). A physically active lifestyle contributes to the prevention of non-communicable diseases such as stroke, diabetes, hypertension, overweight and obesity (World Health Organization, 2018a). It also improves mental health, quality of life and well-being (World Health Organization, 2018b). Walking is a cost-effective form of physical activity, which might appeal to a significant part of the population (Brown et al., 2014; Marselle et al., 2013; National Institute for Health and Clinical Excellence, 2012; World Health Organization, 2014). Moreover, some studies have suggested that conducting physical activity in natural environments brings additional benefits for mental health and well-being (e.g. improves restoration, decreases anger, depression and tension, etc.) compared with conducting physical activity indoors (Bowler et al., 2010; Lahart et al., 2019; Mitchell, 2013; Thompson Coon et al., 2011) or non-natural spaces (Bowler et al., 2010; Mitchell, 2013). However, the evidence is still not conclusive (Lahart et al., 2019; Mitchell, 2013; Thompson Coon et al., 2011).

The aim of this study was to assess psychological and cardiovascular responses of the exposure to blue spaces, compared to urban spaces, and with a control site. Thus, the objectives were: (i) to evaluate changes in well-being and mood responses, blood pressure (BP), and heart rate variability (HRV) after 20 minute walks in a blue space compared with 20 minute walks in an urban space and with resting at a control site; and,

(ii) to assess whether well-being/mood effects were sustained for (at least) 4 hours after the exposure.

2. Methods

2.1. Study design and participants

We applied a randomized crossover design, with participants serving as their own controls. Participants (n=59) were office workers at the Barcelona Biomedical Research Park (PRBB), a research hub at the seafront of Barcelona (Catalonia, Spain). The study was advertised to all members of the PRBB via an internal newsletter sent by email, and posters placed on different parts of the PRBB building.

Inclusion criteria were: working at the PRBB building; available during the whole study period; aged between 18 and 65 years old; non-smokers; not pregnant; not suffering any chronic diseases including high BP (i.e., systolic BP > 139 mmHg and diastolic BP > 89 mmHg) (Pickering et al., 2005), pulmonary diseases, or cardiovascular diseases; not taking medication for hypertension, depression, anxiety, medication for sleep, or any other medication related with any of the chronic diseases listed above; and able to walk for 20 minutes at a constant moderate pace. Before their enrolment in the study (Time 0 – T0), participants attended an informative meeting to receive all the information regarding the aim and the procedure of the study, signed an informed consent, and answered the background questionnaire (Figure 1). Sixty participants were included in the study sample, but one dropped out in the first week due to personal reasons. Thus, 59 participants were finally included.

For study organization reasons and to avoid extreme temperatures on summer or winter, the study was conducted in two different study periods (spring and autumn) of 3 non-necessarily consecutive weeks each (1st period: April – May 2017; 2nd period: September – October 2017), with 29 and 30 participants in each study period respectively. Also, participants were distributed into two turns, the first starting at 10 am and the second at 11.30 am. The study was scheduled on the same weeks for all the participants, with some exceptions when participants occasionally could not attend on the scheduled week. In this case, they were rescheduled for another week. Weather conditions were similar for both study periods (1st period: average temperature=17.0ºC; and average relative humidity (RH)=75.2%. 2nd period: average temperature=16.8ºC; and average RH=66.5%).

During the study period, every day from Monday to Thursday participants came to the study room, either at 10 am (1st turn) or 11.30 am (2n turn), where they were asked to sit and wait for further instructions from the researchers. Measurements and questionnaires were conducted in the study room at Time 1 (T1: before exposure) and Time 3 (T3: immediately after exposure). The time spent in the different environments corresponds to Time 2 (T2) (Figure 1). For the short-term follow-up (Time 4 - T4) we designed an online questionnaire that participants answered 4 hours after the exposure (Figure 1). To standardise the effects on health responses, during T1, T2 and T3, and for all the exposure environments, participants were asked to refrain from talking to each other, using their phone or headphones, reading, eating or drinking anything but water. Moreover, participants were asked to abstain from consuming alcohol at least 12 hours before the measurements (T1), caffeine or food at least 1 hour before (T1) (Gidlow et al., 2016; Grazuleviciene et al., 2016), and practising vigorous physical activity (e.g. running, walking, swimming or cycling fast, competitive sports, etc.) during the morning before T1. No eating, drinking or physical activity restrictions were defined from T3 to T4. Upon completion of the study, participants were paid 150 euros. The study was approved by the Clinical Research Ethics Committee of the Parc de Salut MAR.

2.2. Exposure environments

For each study week, each participant was randomly assigned to a different environment for the whole week (i.e. blue, urban, or control site). Before the start of the study, we assigned a number to each participant and we randomly assigned an exposure to each number for each study week. Thus, all participants were exposed to all environments upon completion of the study. Participants did not know which environment they would be exposed to until the first day of each study week.

We designed a route for both urban and blue environments (Figures 2 and 3). The route on the blue space environment was along the seafront to a breakwater on the beach (Figure 2). The route on the urban space environment was along the sidewalks of nearby PRBB streets (Figure 3). The presence of trees or other green or blue elements along the urban route were avoided as much as possible when designing the route. The starting point of both routes was at the PRBB building, and their length was approximately the same (1.6 km). The control site was in a room at the PRBB (Figure S1 – Supplementary

Material). Details of each environment are described in Table S1 (Supplementary Material). We instructed participants to either walk on their own (i.e., individually) for 20 minutes along the blue or urban route, or to rest for 20 minutes at the control site (Figure S1 – Supplementary Material).

2.3. Health measures

2.3.1. Well-being and mood

Every day, participants completed a set of questionnaires to assess their well-being and mood before (T1) and after (T3 and T4) the exposure. Participants' well-being was also assessed one month upon the completion of the study (Time 5 – T5) (Figure 1). All the questionnaires were completed individually in the study room using tablets, except questionnaires at T4 and T5, which were completed online at home or at the office. Each of these questionnaires included a set of questions targeting specific outcomes (Table 1). The wording of the questions was maintained to retain its purpose. Some of the questions were repeated across the questionnaires (Figure 1).

Subjective well-being (SWB): SWB was assessed using two items from a questionnaire developed by the UK's Office of National Statistics (White et al., 2017). We asked the participants "Overall how happy did you feel yesterday?" and "Overall how anxious did you feel yesterday?". Responses ranged from 0 "Not at all" to 10 "Completely". Given large skews in the distribution of these variables and based on the median (median for happiness=7; median for anxiety=4), we dichotomised these variables.

WHO-5 Well-being: We employed a set of questions adapted from the WHO-5 well-being index (Topp et al., 2015). In our study, we adapted the questions in order to refer to the participant's affective states during the time they were exposed to each environment. Under the statement "During the time that I have been exposed to the [blue/urban route or to the control environment]", participants were asked to answer the following questions: "I have felt cheerful and in good spirits"; "I have felt calm and relaxed"; "I have felt active and vigorous"; "I woke up feeling fresh and rested"; and "My daily life has been filled with things that interest me". Responses included the following options: 0 "At no time"; 1 "Some of the time"; 2 "Less than half the time"; 3 "More than half the time"; 4 "Most of the time"; and 5 "All of the time". As well as

item-specific scores, we created summary scores ranging from 0 (worst quality of life) to 100 (best quality of life) (Topp et al., 2015).

Total Mood Disturbance (TMD): We employed the Spanish short version of the Profile of Mood States (POMS) (Balaguer et al., 1993; Fuentes et al., 1995) to assess total mood disturbance (i.e. psychological distress). It included 29 adjectives, describing different moods, which were classified into 5 subscales: tension/anxiety (TA), depression (D), anger/hostility (AH), fatigue (F), and vigour (V) (Fuentes et al., 1995). Responses were rated on a five-point scale ranging from "Not at all" to "Very much". The total score for TMD was calculated using the following formula: [(TA) + (D) + (AH) + (F) – (V)], indicating the lower the score, the better the mood state. POMS is a well-established measure for which reliability and validity has been previously documented (Fuentes et al., 1995; Song et al., 2019).

Somatisation: The lack of somatisation was assessed every afternoon during the study period. We used an adaptation of the four-dimensional symptom questionnaire (4DSQ) (Terluin et al., 2006), previously used in other studies, e.g. (Triguero-Mas et al., 2017a). We asked participants whether at the moment they were answering the questionnaire they were feeling: "dizziness"; "back/shoulders pain"; "headache"; "painful muscles"; "pain in the chest"; "nausea"; "pain in the abdomen or stomach area"; "ache in the back of the head"; or "fatigue". Responses ranged from 1 "Severely" to 5 "No". We created a sum score of all the items, ranging from 9 to 45. Higher scores indicate lower somatisation symptoms.

Vitality and mental health: We used an adapted version of the SF-36 Health Survey Manual (Ware et al., 1993) to assess vitality and mental health at follow up. For vitality, we asked participants whether at the moment they were answering the questionnaire they were feeling (i) "full of pep and/or energy"; (ii) "worn out"; or (iii) "tired". For mental health, we asked participants whether at the moment they were answering the questionnaire they were feeling (iv) "nervous"; (v) "downhearted"; (vi) "calmed/relaxed"; or (vii) "happy". Possible answers ranged from 5 "No" to 1 "Very much". For three items (i, vi, and vii) answers were scored inversely. The final score was based on the sum of items score for each well-being measure (i.e. vitality and mental health), and transformed to a 0-100 scale according to guidelines (Ware et al., 1993). Higher scores indicated better well-being outcomes.

Sleep characteristics: For assessing sleep characteristics we used a set of questions based on the Pittsburg sleep quality index (Buysse et al., 1988). Under the statement "Please describe how you slept last night" we asked participants the following questions: "I fall asleep easily"; "I felt restless and disturbed"; "I woke up earlier than usual"; "I sleep well"; "Number of hours I slept (hh:mm)". Participants answered "yes", "no", or "I don't know", except for the last question in which they specified the number of hours and minutes they slept the previous night. For this last variable, answers were dichotomised into "<7 hours" and "≥7 hours", considering that this is the adequate sleep duration for healthy adults (Hirshkowitz et al., 2015). For all the variables, we excluded observations whose answer was "I don't know".

General health: To assess self-reported general health we used a single question from the SF-12 Physical and Mental Health Summary Scales (Ware et al., 1995). This was 'How is your health in general?', and participants could answer 1 "Very good", 2 "Good", 3 "Fair", 4 "Bad", or 5 "Very bad". As previously done in other studies (Garrett et al., 2019b), and due to the distribution of the variable, we dichotomised answers into "Good" (for Very good, and Good) and "Not good" (for Fair, Bad and Very bad). This question was previously used in other studies assessing health effects of green or blue spaces (Garrett et al., 2019b; Wheeler et al., 2012).

Life satisfaction: Life satisfaction was measured using one item from a scale developed by the UK's Office of National Statistics (White et al., 2017). In this case, we asked participants "Overall how satisfied are you with life nowadays?". Possible responses ranged from 0 "Not at all" to 10 "Completely".

Eudaimonic well-being: we asked "Overall to what extent do you feel that the things you do in your life are worthwhile?" to assess eudaimonic well-being (White et al., 2017). Possible responses ranged from 0 "Not at all" to 10 "Completely".

2.3.2. Blood pressure and pulse rate

For this study, BP measurements [systolic BP (SBP), diastolic BP (DBP)] and pulse rate (Table 1) were taken at T1 and again at T3 in the study room by trained technicians using a calibrated digital BP monitor (Model M10-IT, OMRON Healthcare, UK) (Figure 1). Before each reading, participants sat down with feet flat on the floor, relaxed and quiet for at least 10 minutes with cuffs placed on their left arm leaning on the table.

We target 3 reliable readings at each study episode (T1 and T3), with pauses of at least 2 minutes in between. We used the mean of the 3 readings for each study episode.

2.3.3. Heart Rate Variability

In this study, HRV (Table 1) was continuously measured from T1 to T3 including the exposure time, T2, using the wireless chest-based wearable device Zephyr BioHarness (Zephyr Technology Corporation, Annapolis, MD, US) (Medtronic, 2019). Raw data were obtained using the BioHarness Log Downloader 9500.0078.V1c (1.0.29.0), processed and cleaned using the R package RHRV (García Martínez et al., 2017). We assessed the presence of ectopic beats, and (both automatically and manually) removed artefacts using algorithms provided by the R package RHRV (García Martínez et al., 2017; Rodríguez-Liñares et al., 2011). Using these algorithms, we rejected values exceeding the cumulative mean threshold, and also those which were not within acceptable physiological values (Rodríguez-Liñares et al., 2011). After estimating the interpolated heart rate signal, we conducted both frequency-domain, and time-domain analysis for each study episode (T1, T2, and T3), estimating a mean value for each.

For the frequency-domain analysis (using the Fourier transformation) we used a time length of 5 minutes (300 seconds), which refers to a short-term length (Massaro and Pecchia, 2019). We obtained heart rate (HR), high frequency (HF; 0.15–0.40 Hz) power, low frequency (LF; 0.05–0.15 Hz) power and the ratio of LF to HF (LF/HF). For the time-domain analysis we used the standard deviation of NN intervals (SDNN), and the root mean square of successive NN interval differences (RMSSD).

2.4. Other measurements

Apart from the indicators mentioned above, we measured other health indicators which were assessed as potential covariables in the different models employed in this study. Participants' body mass index (BMI) was assessed at T0 and again upon the completion of the study, and the mean value between both measurements was calculated. Also, we continuously and quantitatively measured participants' physical activity and sleep quality using ActiGraph GT3X+, a portable device which subjects wore on their non-dominant wrist for 7 consecutive days each week of study participation (starting 3 days prior the start of the study and finishing the day participants completed the whole study week). We used ActiLife software version 6.11.9 for analysing this data (ActiGraph,

2019). We obtained average vector magnitude (VM) and steps to assess (i) weekly records of physical activity, and (ii) physical activity during the time of exposure (using 10-seconds time-window). Sleep quality was assessed using the variables "Total Sleep Time" (total time scored as "asleep") and "Efficiency" (total sleep time divided by total time in bed, in %).

Also, at T3 and T4, participants rated the quality and self-perception of the route they had been exposed to. And at T5 we assessed participants' physical activity levels and visits to natural environments 1 month upon the end of the study (Figure 1).

2.5. Statistical analysis

Two different analysis scenarios were considered. For analysis scenario 1, the control resting exposure was used as reference value, and we compared this with the blue space and the urban space exposure. For analysis scenario 2, we compared the blue space exposure to the urban space exposure (used as a reference).

Well-being and mood: The association between the environments and each of the well-being/mood outcomes were assessed using mixed-effects regression models with participants' ID used as random effects. Specifically, logistic models were used for dichotomous outcomes, reporting odds ratio (OR), and Poisson models were used for count outcomes, reporting incidence-rate ratios (IRR). In both cases, 95% Confidence Intervals (CI) were reported. The effect of different covariates (listed and described in Table S2 – Supplementary Material) in the models was assessed, and we finally adjusted our models by age, gender, the days of the week, and well-being/mood outcomes measured at T1 (when this data was available – see Figure 1). In order to assess whether well-being/mood effects were influenced by participants' health status, we stratified the analysis by good/not good general health according to the "General health" outcome assessed at T3. Also, due to potential differences between women and men in the association between blue space exposure and well-being/mood outcomes (Bell, 2016; Pérez-Tejera et al., 2018; Triguero-Mas et al., 2017a), we assessed interactions between gender and exposure in models with outcomes whose effects were statistically significant.

Blood pressure: For BP, we used mixed-effects linear regression models for continuous variables, reporting coefficients with a 95% CI. We used participants' ID as random

effects. The exposure environment and BP readings at T1 were included as fixed effects. These models were adjusted by age, gender, BMI, and the days of the week. The goodness-of-fit of the models was assessed with the conditional and marginal coefficients of determination (R^2), which are concerned with the variance of the fixed effects, and the fixed effects plus the random effects, respectively (Nakagawa and Schielzeth, 2013).

Heart Rate Variability: These outcomes were measured during T1, T2 and T3 (only domain evaluated during T2). We fit mixed-effects linear regression models with random intercepts for each participant, accounting for an interaction between exposure environment (i.e., control, blue and urban) and study episodes (i.e., T1, T2, and T3) as fixed-effects. As for BP models, the goodness-of-fit was assessed with the conditional and marginal R^2 (Nakagawa and Schielzeth, 2013). Models were adjusted by age, gender, BMI, and the days of the week. To normalize the residuals distribution, HRV parameters were natural log-transformed (Goldberger and Stein, 2019).

Since we acknowledge the relevance of physical activity on BP and HRV results, we conducted sensitivity analysis adjusting BP and HRV models by physical activity quantitatively measured both, weekly and at T2. Given the high correlation between VM and steps (corr.=0.7 for weekly measurements, and corr.=0.8 for T2 measurements), we adjusted our models only by VM.

The statistical analysis was conducted using STATA version 14, and RStudio version 3.5.3. For all the analysis a p-value ≤ 0.05 was considered statistically significant.

3. Results

Fifty-nine healthy adult participants completed the 3-week long study. Participants' characteristics are described in Table 2. Participants rated the blue route significantly better than the urban route, highlighting its better quality, the safety, the lack of garbage and vandalism, and reporting to feel more satisfied when walking along it (Table S3 – Supplementary Material). Perceived air pollution was the main cause of discomfort along the urban route, followed by noise (85% and 75% of the participants rated it badly, respectively), while all ratings of discomfort were lower along the blue route (Table S3 – Supplementary Material).

3.1. Well-being and mood effects

The analysis of well-being/mood outcomes (described in Table 3) showed some differences among the different environments, suggesting better mood and well-being scores when participants were exposed to the blue environment, compared with the urban and control environments (Table 4). The most statistically significant associations were observed for "WHO-5 well-being" and TMD, showing consistency between analysis scenarios 1 and 2 (Table 4). Statistically significant associations were also observed for "Vitality" and "Mental health", although in this case IRR were very close to 1 (Table 4). The only exception was for "sleep duration", which was suggested to be statistically significant higher – and closer to the adequate time sleep for healthy adults – for the urban exposure, compared with the control site. Adjusted models did not differ from the crude models (data not shown).

Subjective well-being (SWB): For SWB we did not observe statistically significant associations (Table 4).

WHO-5 Well-being: For both analysis scenarios, IRR for "Total Well-being Score" was increased when participants were exposed to blue environment (Table 4), suggesting participants' better subjective well-being when they were exposed to this environment [for the blue environment, IRR=1.32 (1.25, 1.38) and IRR=1.34 (1.27, 1.40) in analysis scenario 1 and 2, respectively] compared with the control and urban environments (Table 4).

Total Mood Disturbance (TMD): For both analysis scenarios, IRR for negative TMD sub-scales (TA, D, AH, and F) were significantly lower after walking along the blue route compared with the control and the urban environments [e.g. for the blue environment, IRR=0.36 (95% CI; 0.28, 0.47) for AH in analysis scenario 2]; while IRR for V (i.e. positive TMD sub-scale) was significantly higher [e.g. IRR=1.61 (95% CI; 1.50, 1.73) for V in the blue environment in analysis scenario 1] (Table 4). We also observed a statistically significant higher IRR for AH after walking along the urban route compared with the control [IRR=1.32 (95% CI; 1.09, 1.60)] (analysis scenario 1) (Table 4). We found a decreased IRR for the total score of TMD for both analysis scenarios, suggesting lower TMD when participants were exposed to the blue and urban environments compared with the control, and when they were exposed to the blue environment compared with the urban environment (Table 4).

Somatisation: We did not observe statistically significant associations (Table 4) for somatisation.

Vitality and mental health: "Vitality" and "mental health" measured at the blue and urban environments showed a statistically significant increased IRR (95% CI) for both analysis scenarios, although estimates were very close to 1 [e.g. IRR=1.07 (95% CI; 1.04, 1.09) for "Vitality" in the blue environment in analysis scenario 2] (Table 4).

"Somatisation", "vitality" and "mental health" were measured at T4. These results suggest no consistency of the persistence over time of the well-being effects associated with blue spaces' exposure.

Sleep characteristics: We observed a lower OR for sleeping less than 7 hours/day (vs. sleeping at least 7 hours/day) when participants were exposed to the urban environment compared with the control, although no statistically significant associations were found for any of the other variables describing sleep characteristics (Table 4).

General health, life satisfaction, and eudaimonic well-being: We did not observe statistically significant associations for any of these outcomes (Table 4).

For the outcomes that showed statistically significant associations (i.e. "WHO-5 well-being", TMD and "Vitality" and "mental health"), we stratified the models by "General health" (assessed within a questionnaire at T3). For "WHO-5 well-being", "Vitality" and "mental health" we observed better scores among non-healthy participants compared with healthy participants (Table S4 – Supplementary Material). This was not observed for TMD (Table S4 – Supplementary Material). No statistically significant interactions were observed between gender and the exposure environments for TMD, neither for "Vitality" and "Mental health" (data not shown). For "WHO-5 well-being", we observed a statistically significant interaction between gender and the exposure environment, for "Total Well-being score" in analysis scenario 1 (p-value=0.02) (data not shown). In this case, the effect of blue spaces exposure appeared to be stronger for women than for men (Table S5 – Supplementary Material).

3.2. Blood pressure and pulse rate

The descriptive analysis of BP and pulse rate, with pairwise comparisons between T1 and T3 with Bonferroni corrections, showed only statistically significant differences of SBP and pulse rate in the control site (Table S6 – Supplementary Material).

In the same line, we found statistically significant increased SBP and pulse rate in the blue and urban environments compared with the control site (analysis scenario 1) [e.g. SBP for subjects exposed to blue environment: coef. =1.16 (95% CI: 0.26, 2.06)] (Table 5). However, no statistically significant associations were observed in analysis scenario 2 (Table 5). Results for the adjusted models did not differ from those of the crude models (Table S7 – Supplementary Material).

Results from the sensitivity analysis, with models adjusted by physical activity levels, showed no statistically significant associations for SBP, DBP, and neither pulse rate for any of the two different analysis scenarios (Table S8 – Supplementary Material).

Physical activity levels, quantitatively assessed with VM, showed no statistically significant differences between exposure environments (Table S9 – Supplementary Material).

3.3. Heart Rate Variability

The descriptive analysis of HRV variables, with pairwise comparisons with Bonferroni corrections, can be found at the Supplementary Material (Table S10 – Supplementary Material). The description of logarithmic HRV variables, by exposure environment and study period, are also graphically represented (Figure 4).

We found statistically significant interaction between exposure environments and study period in analysis scenario 1, and in analysis scenario 2, in this case only for LF and HF (Table S11 – Supplementary Material). In the analysis of association (Table 6), we found statistically significant increased HR and LF/HF; and statistically significant decreased LF, HF, SDNN, and RMSSD when participants were exposed to the blue and urban environments, compared with the control (analysis scenario 1). This is an indicator of a stimulation of the sympathetic nervous system (SNS), related with increased activity levels (European Society of Cardiology, 1996; García Martínez et al., 2017; Laeremans et al., 2018; Shaffer and Ginsberg, 2017; Song et al., 2019, 2015; Stigsdotter et al., 2017; Valenza et al., 2018). We also observed increased LF/HF, and decreased LF, HF, SDNN, and RMSSD, when we compared estimates of the blue

exposure with those in the urban exposure (analysis scenario 2), although in this case it was only statistically significant at T2 (during exposure) and the association was weaker than in analysis scenario 1 (Table 6). No statistically significant associations were observed in analysis scenario 2 at T3 (after exposure), when all the values were very close to zero (Table 6). Thus, suggesting no differences on HRV parameters, between the urban and the blue environments at T3. Crude models showed very similar results (Table S12 – Supplementary Material).

In the sensitivity analysis (Table S13 – Supplementary Material), when the model was adjusted by VM at T2, we found a weaker effect of the exposure environments and study period on HRV parameters in analysis scenario 1. However, the direction of the association was consistent with the main model (Table 6). In analysis scenario 2 (Table S13 – Supplementary Material), the sensitivity analysis showed no differences with the main model. Finally, when the model was adjusted by weekly VM (as a proxy of the baseline physical activity levels of the study population), the estimates of the sensitivity analysis (Table S13 – Supplementary Material) did not differ from those of the main model (Table 6).

The goodness-of-fit of mixed-effects linear regression models employed in this study to evaluate the association between exposure environments and BP and HRV was assessed with R^2 (Tables 4-5) and scatter plots (data not shown). These showed homoscedasticity and a normal distribution of the residuals. Hence, both the R^2 and the scatter plots, suggested an adequate goodness-of-fit of the models employed in this study.

4. Discussion

4.1. Main findings

In this study we observed better well-being and mood responses shortly after walking 20 minutes in a blue space versus walking in an urban space (analysis scenario 2) or resting in a control site (analysis scenario 1). Nevertheless, there was no evidence that BP and pulse rate decreased in the blue space exposure, compared with the urban space (analysis scenario 2) or the control site (analysis scenario 1). Also, cardiovascular responses showed unexpected findings by suggesting an increased activity of the SNS not only during the time participants walked in either the blue or the urban space compared with resting in the control site, but also after that (analysis scenario 1), when

we would expect an increased dominance of the parasympathetic nervous system (PNS) (Goldberger and Stein, 2019). Similar effects on cardiovascular outcomes were observed during the time participants walked in the blue space, compared to the urban space (analysis scenario 2), although the association was weaker in this case. Results of analysis scenario 1 highlight the importance of moderate physical activity on cardiovascular health, regardless of the environment in which it is being practised.

Psychological responses seemed to be not only influenced by physical activity, but also by the type of environment, being better when participants were exposed to blue space. Furthermore, our results suggest better psychological responses among participants reporting bad general health status, and – for some outcomes – also among women. Positive effects on mental health have already been reported by other experimental studies whose participants were exposed to – either natural or artificial – nature views while being sedentary (Bielinis et al., 2018; Gilchrist et al., 2015; Mangonea et al., 2017). Well-being benefits as a consequence of being in contact with nature have been broadly described (Bratman et al., 2019; Frumkin et al., 2017) and might be explained by the biophilia hypothesis (Wilson, 1984), suggesting human's affinity to nature and its positive well-being consequences when this is accomplished (Nieuwenhuijsen et al., 2017; Yeager et al., 2019).

Physical activity is related with an activation of the SNS activity, and a deactivation of the PNS activity (Goldberger and Stein, 2019). This situation is characterized by an increase of HR and LF/HF, and a decrease of HF and LF (highly correlated with RMSSD and SDNN, respectively) (Castaldo et al., 2015; García Martínez et al., 2017; Shaffer and Ginsberg, 2017). This expected situation during physical activity periods is observed for HRV parameters at T2. However, even though our results suggest a potential reactivation of the PNS [responsible for recovering the normal cardiovascular situation (García Martínez et al., 2017; Massaro and Pecchia, 2019)] at T3, the estimates still do not indicate the complete rebalance of the PNS and SNS activities. We hypothesized that participants would be more relaxed after walking in a blue space than in an urban space, as suggested by other similarly designed studies (e.g., Lee et al., 2011; Song et al., 2019; Triguero-Mas et al., 2017b). However, this was not observed in our study. On the same line, BP and pulse rate were supposed to increase due to physical activity and decrease on the recovery (T3), showing better results for the blue space than for urban space. In this study, BP and pulse rate were higher after the

exposure (T3), being statistically significant for SBP and pulse rate in analysis scenario 1 (Table 5). We did not find a decreased BP or pulse rate after the exposure in the blue space, neither in the urban space.

4.2. Strengths and limitations

In our study we did not observe positive cardiovascular effects of being exposed to a blue space, as other similarly designed studies with green spaces' exposure suggested (Lee et al., 2011; Song et al., 2019, 2015, 2014, 2013; Triguero-Mas et al., 2017b). We acknowledge some study limitations that might explain our results. The post-exposure assessment was shortly after the exposure, which included moderate physical activity when participants were exposed to the blue and urban environment. Physical activity, which requires energy expenditure, increases the SNS activity and decreases the PNS activity (Castaldo et al., 2015; García Martínez et al., 2017; Goldberger and Stein, 2019). Subsequently, the SNS and PNS activity would rebalance and an increased PNS activity would suggest better health and a greater state of relaxation. However, post-exposure parameters of this study might be assessed too close to the exposure period, not having enough time to recover the PNS and SNS activities from the physical activity stimulus. A longer time period between the exposure and the post-exposure assessment, such as 20 minutes (instead of 10 minutes as in our study), might be required to observe cardiovascular effects produced by the exposure (urban or blue space environment) and not by physical activity (Torrente et al., 2017; Triguero-Mas et al., 2017b). Also, in our study we evaluated acute effects of short walks along blue spaces. A continuous long-lasting exposure to blue spaces, being or not moderately active, might result in positive effects on cardiovascular health that cannot be identified with our study design because blue spaces' exposure may lead to longer lasting cardiovascular effects than exposure to urban spaces. Based on previous literature, we defined an exposure duration of 20 minutes in order to facilitate participants' engagement in the study, given that the study was conducted during working hours. Even though other similar studies observed positive health effects even after 15 minutes walks on green spaces (Bielinis et al., 2018; Song et al., 2019, 2015, 2013), we acknowledge that our results might be underestimations and that we might have observed greater health benefits with a longer exposure period. The exposure time-length and the intensity and type of physical activity conducted by the participants – who reported to be very active (see Table 2) – might be insufficient to promote changes

in healthy adults' baseline BP or HRV with normal ranges. Besides this, outcomes selected to assess changes on cardiovascular health between environments, might not be sensitive enough for this purpose. Apart from that, we acknowledge that the observed health estimates might have been different if we assessed participants' exposure to blue or urban spaces while sitting or standing instead of walking, as similarly done before (e.g., Bielinis et al., 2018; Lee et al., 2011). Thus, it would be interesting to replicate the study with the mentioned modification. Beyond physical activity, it is also well-known that air pollution might have an effect on cardiovascular health (Nieuwenhuijsen, 2018). In our analysis we did not find evidence for adjusting our BP and HRV models by air pollution, thus air pollution was not included as a covariable. However, air pollution measurements available for this study correspond to those measured in a station next to PRBB. Air pollution measurements specifically measured in the urban and in the blue route might better represent air pollution levels in each exposure environments but could not be used because this data was not available. Apart from that, in the current study we used a study sample whose characteristics might have underestimated the expected health effects. As shown in Table 2, 88% of the participants reported to have views to blue spaces from their workplace. This is no surprise given that the PRBB is in front of the sea. We hypothesize that greater effects on well-being and mood would be observed among participants who are not usually exposed to blue spaces. Also, participants of this study were healthy adults, physically active and highly educated, threatening the generalization of the study results. Cardiovascular effects of short walks on blue spaces might be observed using a similar study design with hypertensive, obese, and/or older participants. Finally, given that questions were repeated every day (sometimes even twice a day: i.e., at T1 and T3) for four days, we cannot discard a fatigue effect on participants. However, the repeated questionnaires to assess the well-being and mood of the participants were designed to be short, with an average answer time of 5 minutes approximately, in order to reduce the burden for the participants as much as possible.

Strengths of this study include the randomized cross-over design, that well-being/mood and BP models were adjusted by baseline measures (except for some mood and well-being outcomes that were not measured at baseline), that we accounted for an interaction between exposure environment and study episodes in the HRV models, and that the blue environment could be compared not only with urban environment, but also

with a control site. Thus, each participant served as their own control, reducing the risk of bias. Also, we used different (and most of them validated) questions to identify a wide range of changes on well-being and mood, not only focusing on a specific outcome. Furthermore, our results are consistent with those found in other similarly designed studies, reporting better well-being and mental health outcomes after walking along natural environments (Bielinis et al., 2018; Bratman et al., 2015; Brown et al., 2014; Gidlow et al., 2016; Koselka et al., 2019; Song et al., 2019; Triguero-Mas et al., 2017a). However, most of these other studies compared urban versus green spaces, while we evaluated exposure to blue spaces, rarely done before (for exceptions see Gidlow et al., 2016; Triguero-Mas et al., 2017a). Finally, this is, to our knowledge, one of the very few studies evaluating the effects of blue spaces exposure on people's health that uses repeated acute exposures instead of single exposures (for exceptions see Brown et al., 2014; Koselka et al., 2019), and our unexpected findings on cardiovascular responses are consistent with another study using repeated acute exposures (Brown et al., 2014).

4.3. Future research

Despite our null results for cardiovascular effects of blue spaces exposure, it is key to keep considering this outcome in further studies given that cardiovascular diseases are still a leading cause of mortality worldwide (Nieuwenhuijsen, 2018) and because previous research has found favorable changes in HRV indicators in blue environments (Triguero-Mas et al., 2017b). Nature's contact benefits our physiological and psychological health (WHO Regional Office for Europe, 2016) and this is even more relevant in the urbanization context we are living nowadays (Bratman et al., 2019). People's nature affinity has also been observed in this study: most of the participants positively rated the experience of walking along the blue space, and we observed positive effects for well-being and mood.

The evaluation of health benefits associated to blue space's exposure has gained more attention recently. However, there are still some knowledge gaps that require more research (Gascon et al., 2017). For example, potentially differing health effects depending on the type of blue space people are exposed to. While we observed positive well-being and mood effects on participants when they were exposed to the blue environment, in our case an urban beach, it is not clear whether these effects would be

magnified or reduced if the blue space had been a river, a lake, or a fountain instead of an urban beach. The wildness and other characteristics (such as type, quality or context) of the selected site could influence the magnitude of the health effects observed in this study (Cheesbrough et al., 2019; Wheeler et al., 2015).

5. Conclusions

Compared to walking along an urban space environment, short walks in a blue space environment (urban beach) can benefit both well-being and mood. However, we did not observe differences regarding cardiovascular outcomes.

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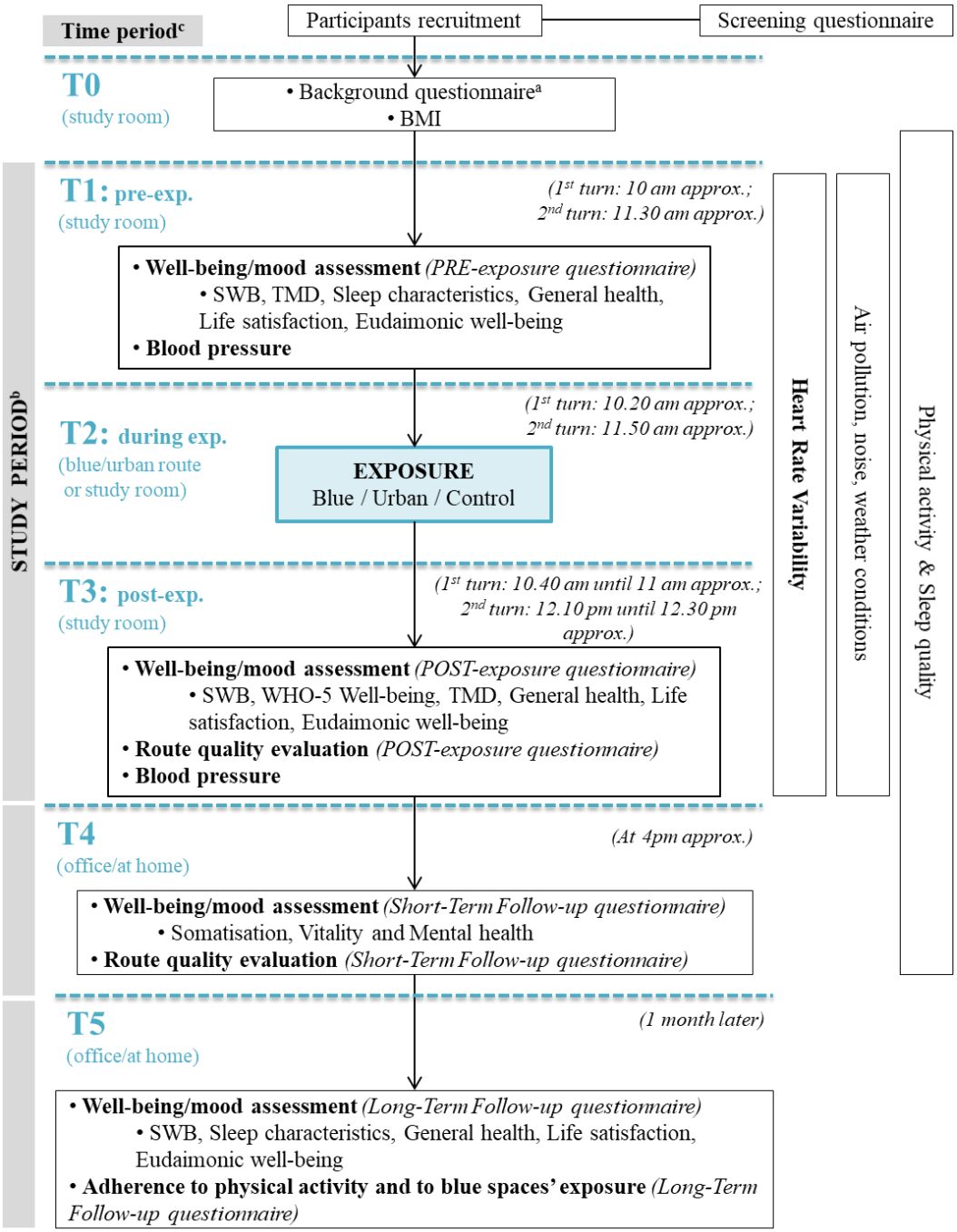
Tables and Figures

Figure 1. Flowchart of the study procedure.



[a]Background questionnaire includes questions about participants' socioeconomic characteristics, natural spaces' exposure and use, and physical activity.

[b]This study was carried out for 3 non-necessarily consecutive weeks, with participants' involvement in the study 4 days/week (Monday to Thursday). The study procedure, from T1 to T4, was the same every day. Participants were distributed into 2 turns and every day participants took part in the study during the time slot of their turn: the 1st turn was from 10 am to 11 am, and the 2nd turn was from 11.30 am to 12.30 am. The short-term follow-up questionnaire was sent to participants every day of the study period at 4 pm approximately, thus at least 3.5h after study participation.

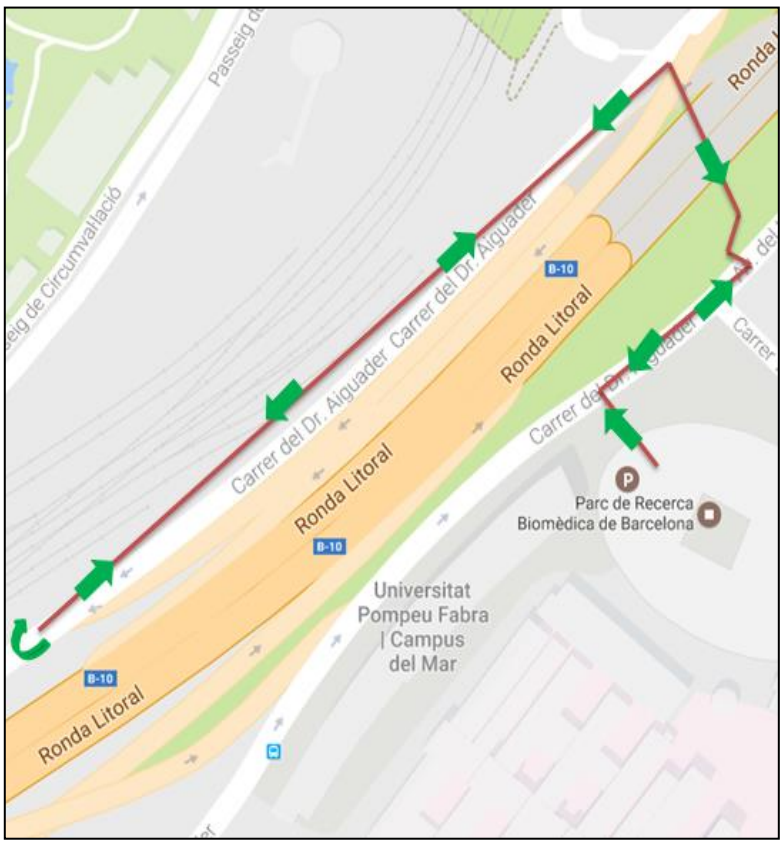
[c]Time period refers to the moment when the different variables were measured. Time=0 (T0): baseline; Time=1 (T1): pre-exposure; Time=2 (T2): during exposure; Time=3 (T3): post-exposure; Time=4 (T4): short-term follow-up; Time=5 (T5): long-term follow-up.

Figure 2. Blue route: **(a)** Route followed by the participants when they were randomly assigned to the blue space exposure (Google Maps) **(b)** Image of a section of the blue route, at the breakwater in the beach (*Espigó del Gas*). Photo taken by: Cristina Vert, October 2019.

(a)

(b)

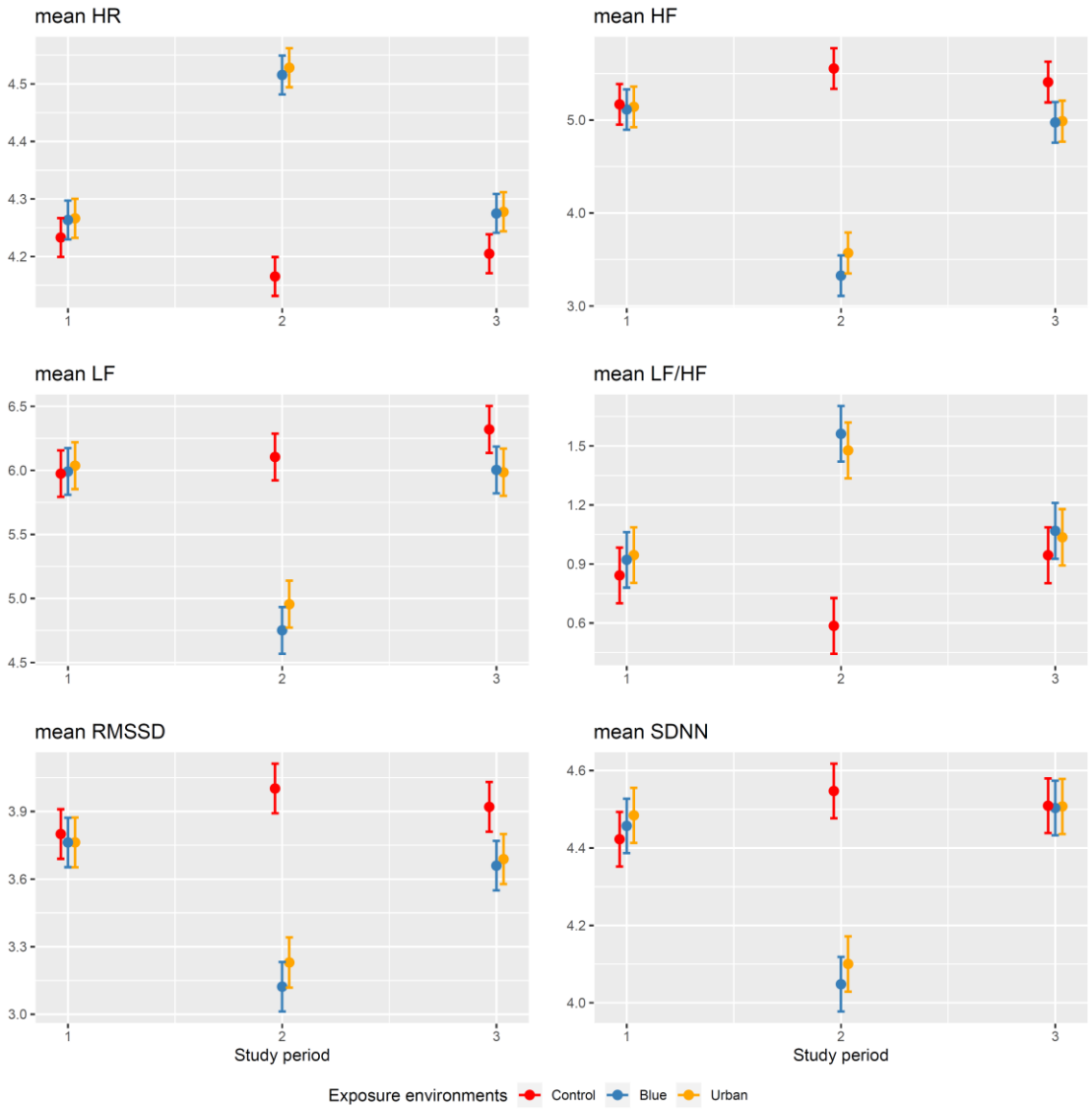
Figure 3. Urban route: **(a)** Route followed by the participants when they were randomly assigned to the urban space exposure (Google Maps) **(b)** Image of a section of the urban route, on the sidewalk next to the road. Photo taken by: Cristina Vert, October 2016.



(a)

(b)

Figure 4. Mean logarithmic HRV variables*, by exposure environment and study period (i.e., T1, T2, T3).



*HRV variables: heart rate (HR), low frequency power (LF), high frequency power (HF), and the ratio of LF to HF (LF/HF); and (ii) time domain measurements: standard deviation of NN interval (SDNN), and the root mean square of successive NN interval differences (RMSSD).

Table 1. Description of the aim to assess each of the variables considered in the health measures evaluated in the study.

Health measures	**Variables**	**What we aim to assess (and time period of assessment)**
Well-being and mood	SWB	Overall well-being perception of the participants (T1, T3, T5)
	WHO-5 well-being	Participant's affective states during the time they were exposed to each environment (T3)
	TMD	Psychological distress based on the rating of different (positive and negative) adjective representing different moods (T1, T3)
	Somatisation	Lack of somatisation symptoms, assessed at follow-up (T4)
	Vitality and mental health	Overall well-being assessed at follow-up (T4)
	Sleep characteristics	Sleep quality, which might influence well-being and mood (T1, T5)
	General health	Reflects the own health status perceived by the participants and it is highly associated with more complex and objective dimensions of physical and psychological health (T1, T3, T5)
	Life satisfaction	Evaluative wellbeing to identify how well participants think their life is going overall (T1, T3, T5)
	Eudaimonic well-being	Participant's self-perception of the meaningfulness and worthwhile of their behaviours and activities (T1, T3, T5)
BP	SBP DBP Pulse rate	High blood pressure (assessed with SBP and DBP) is a risk factor for cardiovascular diseases. Also, both blood pressure and pulse rate (and HR, see below), are indicators of the state of the participants in terms of nervousness or physiological relaxation. Reduced blood pressure and pulse rate is considered a positive health indicator when it implies a reversion of elevated rates to healthy levels (T1, T3)
HRV	HR HF	HRV reflects the balance of the autonomous nervous system, which

	LF LF/HF SDNN RMSSD	includes SNS and PNS. An activation of the PNS (characterised by a decreased HR and LF/HF, and an increased HF and LF, highly correlated with RMSSD and SDNN, respectively) would suggest physiological relaxation (T1, T2, T3)

SWB: subjective well-being. TMD: Total Mood Disturbance. SBP: Systolic blood pressure. DBP: Diastolic blood pressure. HR: heart rate. HF: high frequency power (0.15–0.40 Hz). LF: low frequency power (0.05–0.15 Hz). LF/HF: ratio of LF to HF. SDNN: standard deviation of NN intervals. RMSSD: root mean square of successive NN interval differences. SNS: sympathetic nervous system. PNS: parasympathetic nervous system.

(Balaguer et al., 1993; Fuentes et al., 1995; García Martínez et al., 2017; Rodríguez-Liñares et al., 2011; Shaffer and Ginsberg, 2017; Terluin et al., 2006; Topp et al., 2015; Triguero-Mas et al., 2017b; Ware et al., 1995, 1993; White et al., 2017)

Table 2. Participants characteristics (n=59).

Parameter	Category	n (%)
Gender	Women	41 (69.5)
Age [mean (min; max)]		29 (19;49)
Education	University degree	56 (94.9)
Perceived household income	Feeling comfortable	30 (50.9)
Marital status	Married, couple or civil union	21 (35.6)
Residential access natural spaces (blue and/or green)	Yes	10 (17.0)
Views blue spaces at work	Yes	52 (88.1)
Access private open space	Yes	37 (62.7)
Blue space exposure during childhood	Yes	49 (83.1)
Meeting physical activity WHO guidelines[a]	Yes	53 (89.8)
BMI (kg/m^2) [mean (min; max)]		22.6 (17.1; 35.1[b])

[a]WHO guidelines recommend to the adult population to do at least 150 minutes of moderate-intensity physical activity, or 75 minutes of vigorous-intensity physical activity throughout the week, or an equivalent combination of moderate- and vigorous-intensity activity (World Health Organization, 2018a). In this case, this variable refers to the self-reported physical activity conducted during the last 7 days (assessed with the Background questionnaire, at T0, and considered as the baseline measure of self-reported physical activity).

BMI: body mass index. SBP: Systolic blood pressure. DBP: Diastolic blood pressure.

[b]Although the maximum value of BMI was 35.5 kg/m^2, among the whole study sample there was only one subject with BMI>30 kg/m^2 (corresponding to Obesity Class I according to WHO (WHO Regional Office for Europe, 2019)). And six subjects had a BMI between 25 and 29.9 kg/m^2 (corresponding to Pre-obesity according to WHO (WHO Regional Office for Europe, 2019)). A sensitivity analysis excluding subjects whose BMI>25 kg/m^2 was conducted, showing similar results than those reported in Table 4 (data not shown).

Table 3. Descriptive statistics of well-being and mood variables.

	Exposure			
	Control	**Blue**	**Urban**	**p-value**
Subjective well-being (SWB) [%]				
PRE Exposure (T1)				
Yesterday I felt happy	61.0	52.5	59.3	0.62
Yesterday I felt anxious	23.7	27.1	27.1	0.89
POST exposure (T3)				
Yesterday I felt happy	47.5	48.3	44.1	0.89
Yesterday I felt anxious	49.2	37.9	42.4	0.47
WHO-5 Well-being [%]				
I have felt cheerful and in good spirits (yes)	29.0	44.9	26.2	<0.01*
I have felt calm and relaxed (yes)	35.9	42.7	21.4	<0.01*
I have felt active and vigorous (yes)	15.2	52.2	32.6	<0.01*
I woke up feeling fresh and rested (yes)	31.5	37.0	31.5	0.63
My daily life has been filled with things that interest me (yes)	32.4	36.0	31.5	0.52
Total Well-being Score [a] [mean (std.dev.)]	47.9 (18.3)	63.2 (15.7)	47.1 (19.7)	<0.01*
Total Mood Disturbance (TMD) [mean (std.dev.)]				
PRE Exposure (T1)				
Tension/Anxiety[b] (TA)	4.4 (3.2)	4 (2.4)	4.4 (3.8)	0.56
Depression[b] (D)	0.9 (2.2)	0.8 (2.2)	1 (2.8)	0.73
Anger/Hostility[b] (AH)	1 (2.3)	0.8 (2.3)	1.4 (3.3)	0.16
Fatigue[c] (F)	1.5 (2.3)	1.4 (2.3)	1.9 (3)	0.93
Vigour[b] (V)	9.6 (5.4)	9.9 (5.6)	9.6 (5.2)	0.94
Total score POMS[d]	98.3 (10.4)	97.3 (9.6)	99.1 (12.2)	0.57
POST exposure (T3)				
Tension/Anxiety[b] (TA)	4.4 (2.6)	3.9 (2)	4.6 (3)	0.23
Depression[b] (D)	1 (2.2)	0.7 (2.2)	0.7 (1.9)	0.09
Anger/Hostility[b] (AH)	1.1 (2.7)	0.5 (1.5)	1.4 (2.7)	<0.01*
Fatigue[c] (F)	1.9 (2.3)	1 (1.6)	1.6 (2.5)	<0.01*

Vigour[b] (V)	7 (5)	11.3 (5.7)	10 (5)	<0.01*
Total score POMS[d]	101.4 (9.7)	94.8 (8.7)	98.4 (10.1)	<0.01*
No somatisation index[e] [mean (std.dev.)]	40.4 (2.6)	40.7 (2.5)	40.2 (3.5)	0.35
Vitality and mental health (SF36) [mean (std.dev.)]				
Vitality[f]	62.9 (18.5)	67.9 (18.4)	63.2 (19.3)	0.02*
Mental health[f]	64.7 (19.2)	69.1 (18.3)	65.6 (19.1)	0.04*
Sleep characteristics[g] (last night) (T1) [%]				
Sleep latency ("Fall asleep easily")	84.4	85.7	76.8	0.03
Sleep disturbance ("Restless and disturbed")	24.1	25.6	25.4	0.93
"Wake up earlier than usual"	21.4	29.2	25.0	0.17
Sleep quality ("Sleep well")	79.5	79.8	78.5	0.94
Sleep duration ("Short time sleeping (<7h)")	33.0	35.9	34.7	0.82
General health (good) [%]				
PRE exposure (T1)	93.22	91.53	91.53	0.93
POST exposure (T3)	86.44	91.38	93.22	0.44
Life satisfaction [mean (std.dev.)]				
PRE exposure (T1)	7.4 (1.4)	7.3 (1.4)	7.2 (1.4)	0.56
POST exposure (T3)	7.4 (1.3)	7.3 (1.4)	7.2 (1.6)	0.94
Eudaimonic well-being [mean (std.dev.)]				
PRE exposure (T1)	7.1 (1.6)	7.2 (1.4)	7.2 (1.6)	0.92
POST exposure (T3)	7.2 (1.4)	7.3 (1.5)	6.9 (1.7)	0.40

To assess statistically significant outcomes' differences between exposures, we conducted Kruskal-Wallis tests for continuous dependent variables, and chi-square or Fisher's exact tests for categorical dependent variables. We used a 0.05 level of significance (with an * showing statistically significant results).

[a]Score ranging from 0 to 100, illustrating the worst and best scenario, respectively.

[b]Score ranging from 0 "Not at all" to 24 "Very much".

[c]Score ranging from 0 "Not at all" to 20 "Very much".

[d]Lower score indicates better mental health.

[e]Minimal potential score was 9 (representing the highest somatisation index), and maximum potential score was 45 (representing the lowest somatisation index).
[f]Score ranging from 0 (representing low vitality and mental health) to 100 (representing high vitality and mental health).
[g]Sleep characteristics categories have been defined according to The Pittsburgh Sleep Quality Index (PSQI) (Buysse et al.. 1988).

Table 4. Association between environments of exposures (i.e. control, blue, urban) and well-being and mood (analysis scenario 1 and 2)[a]

	Exposure (analysis scenario 1)			Exposure (analysis scenario 2)	
	Control	**Blue**	**Urban**	**Urban**	**Blue**
	ref.	IRR[b] (95% CI)	IRR[b] (95% CI)	ref.	IRR[b] (95% CI)
Subjective well-being (SWB)					
Yesterday I felt happy	ref.	1.20 (0.52, 2.73)	0.93 (0.41, 2.13)	ref.	1.38 (0.62, 3.06)
Yesterday I felt anxious	ref.	0.55 (0.23, 1.29)	0.67 (0.28, 1.58)	ref.	0.78 (0.28, 2.16)
WHO-5 Well-being					
I have felt cheerful and in good spirits	ref.	1.45 (1.18, 1.80)*	1.00 (0.79, 1.25)	ref.	1.50 (1.22, 1.86)*
I have felt calm and relaxed	ref.	1.11 (0.91, 1.35)	0.70 (0.56, 0.88)*	ref.	1.62 (1.31, 2.01)*
I have felt active and vigorous	ref.	2.46 (1.90, 3.19)*	1.83 (1.39, 2.40)*	ref.	1.38 (1.11, 1.71)*
I woke up feeling fresh and rested	ref.	1.04 (0.82, 1.33)	0.92 (0.71, 1.17)	ref.	1.15 (0.89, 1.47)
My daily life has been filled with things that interest me	ref.	1.09 (0.87, 1.35)	1.01 (0.81, 1.26)	ref.	1.07 (0.82, 1.40)
Total Well-being Score	ref.	1.32 (1.25, 1.38)*	0.99 (0.94, 1.05)	ref.	1.34 (1.27, 1.40)*
Total Mood Disturbance (TMD)					
Tension/Anxiety (TA)	ref.	0.95 (0.86, 1.06)	1.07 (0.97, 1.19)	ref.	0.88 (0.80, 0.98)*
Depression (D)	ref.	0.72 (0.57, 0.91)*	0.82 (0.66, 1.04)	ref.	0.85 (0.66, 1.08)
Anger/Hostility (AH)	ref.	0.51 (0.40, 0.66)*	1.32 (1.09, 1.60)*	ref.	0.36 (0.28, 0.47)*
Fatigue (F)	ref.	0.55 (0.46, 0.66)*	0.80 (0.68, 0.94)*	ref.	0.68 (0.56, 0.82)*
Vigour (V)	ref.	1.61 (1.50, 1.73)*	1.44 (1.34, 1.55)*	ref.	1.12 (1.05, 1.20)*
Total score POMS	ref.	0.94 (0.92, 0.96)*	0.97 (0.95, 0.99)*	ref.	0.97 (0.95, 0.99)*
No somatisation index	ref.	1.01 (0.97, 1.04)	1.00 (0.97, 1.03)	ref.	1.02 (0.86, 1.20)
Vitality and mental health (SF36)					
Vitality	ref.	1.08 (1.06, 1.11)*	1.01 (0.99, 1.04)	ref.	1.07 (1.04, 1.09)*
Mental health	ref.	1.08 (1.05, 1.10)*	1.02 (1.00, 1.05)	ref.	1.05 (1.03, 1.08)*
Sleep characteristics[f] (last night)					
Sleep latency (“Fall asleep easily”)	ref.	2.35 (0.83, 6.65)	0.87 (0.36, 2.11)	ref.	2.61 (0.93, 7.32)
Sleep disturbance (“Restless and disturbed”)	ref.	0.68 (0.29, 1.58)	0.73 (0.32, 1.70)	ref.	0.91 (0.39, 2.14)

"Wake up earlier than usual"	ref.	1.10 (0.47, 2.59)	0.65 (0.26, 1.62)	ref.	1.62 (0.67, 3.91)
Sleep quality ("Sleep well")	ref.	1.71 (0.71, 4.13)	1.15 (0.50, 2.66)	ref.	1.50 (0.62, 3.63)
Sleep duration ("Short time sleeping (<7h)")	ref.	0.65 (0.26, 1.63)	0.34 (0.13, 0.92)*	ref.	1.83 (0.68, 4.96)
General health (good)	ref.	4.49 (0.51, 39.24)	9.17 (0.79, 107.11)	ref.	0.56 (0.07, 4.60)
Life satisfaction	ref.	1.20 (0.34, 4.26)	1.28 (0.35, 4.63)	ref.	0.90 (0.29, 2.76)
Eudaimonic well-being	ref.	1.51 (0.51, 4.47)	0.73 (0.24, 2.20)	ref.	2.18 (0.68, 6.70)

*p-value≤0.05

[a]All the models were adjusted by age, gender, day of the week, and well-being/mood measured at T1 (when this data was available – see Figure 1). Except for *"SWB", "General health", "Life satisfaction",* and *"Eudaimonic well-being"*, that could not be adjusted by day of the week, because these variables were measured only on the first and last day of each study week, but not the whole days of the study week.

[b]IRR=Incidence Rate Ratio. For dichotomous dependent variables we conducted logistic regression models, reporting odds ratio (OR) instead of IRR. Dichotomous dependent variables were: "*Subjective well-being*", "*Sleep characteristics*", "*General health (good)*", and "*Life satisfaction*".

Table 5. Association between exposure environments (i.e. control, blue, urban) and BP (measured at T3)[a]. BP variables included systolic blood pressure (SBP), diastolic blood pressure (DBP), and pulse rate.

	Analysis scenario 1			**Analysis scenario 2**		**Conditional $R^{2\,b}$**	**Marginal $R^{2\,b}$**
	Control	**Blue**	**Urban**	**Urban**	**Blue**		
		Coef. (95% CI)	Coef. (95% CI)		Coef. (95% CI)		
SBP	ref.	1.16 (0.45, 1.87)*	1.27 (0.57, 1.98)*	ref.	-0.09 (-0.82, 0.65)	0.830	0.767
DBP	ref.	0.39 (-0.09, 0.88)	0.20 (-0.28, 0.67)	ref.	0.22 (-0.27, 0.70)	0.771	0.368
Pulse rate	ref.	2.08 (1.48, 2.67)*	1.87 (1.27, 2.46)*	ref.	0.21 (-0.39, 0.81)	0.794	0.141

[a]Models adjusted by: age, gender, body mass index (BMI), days of the week, and BP measured at T1.

[b]The goodness-of-fit of this model has been assessed with the conditional and marginal R^2, which are concerned with the variance of the fixed effects, and the fixed effects plus the random effects, respectively (Nakagawa and Schielzeth, 2013).

*Statistically significant (p-value≤0.05)

Table 6. Association between exposure environments (i.e. control, blue, urban) and logarithmic HRV variables. HRV variables included (i) frequency domain measurements: heart rate (HR), low frequency power (LF), high frequency power (HF), and the ratio of LF to HF (LF/HF); and (ii) time domain measurements: standard deviation of NN interval (SDNN), and the root mean square of successive NN interval differences (RMSSD).

		Analysis scenario 1			**Analysis scenario 2**		**Cond. $R^{2\,b}$**	**Marg. $R^{2\,b}$**
		Control	**Blue**	**Urban**	**Urban**	**Blue**		
	Time period[a]		Coef. (95% CI)	Coef. (95% CI)		Coef. (95% CI)		
Ln(HR)	T1	ref.	0.021 (0.006, 0.037)*	0.025 (0.010, 0.041)*	ref.	-0.004 (-0.021, 0.013)		
	T2	ref.	0.363 (0.347, 0.379)*	0.369 (0.353, 0.384)*	ref.	-0.005 (-0.022, 0.011)	0.835	0.500
	T3	ref.	0.072 (0.056, 0.088)*	0.077 (0.061, 0.093)*	ref.	-0.005 (-0.021, 0.012)		
Ln(LF)	T1	ref.	-0.009 (-0.112, 0.094)	-0.009 (-0.111, 0.095)	ref.	-0.007 (-0.117, 0.103)	0.724	0.437
	T2	ref.	-1.390 (-1.493, 1.288)*	-1.230 (-1.333, -1.127)*	ref.	-0.167 (-0.277, -0.057)*		
	T3	ref.	-0.295 (-0.398, -0.193)*	-0.341 (-0.445, -0.238)*	ref.	0.039 (-0.070, 0.149)		
Ln(HF)	T1	ref.	-0.047 (-0.177, 0.083)	-0.057 (-0.188, 0.074)	ref.	0.003 (-0.136, 0.142)	0.744	0.395
	T2	ref.	-2.276 (-2.406, -2.146)*	-2.059 (-2.190, -1.929)*	ref.	-0.224 (-0.363, -0.085)*		
	T3	ref.	-0.415 (-0.545, -0.285)*	-0.425 (-0.555, -0.294)*	ref.	0.003 (-0.136, 0.141)		
Ln(LF/HF)	T1	ref.	0.045 (-0.042, 0.132)	0.056 (-0.031, 0.144)	ref.	-0.012 (-0.104, 0.080)	0.646	0.218
	T2	ref.	0.980 (0.892, 1.067)*	0.884 (0.796, 0.971)*	ref.	0.095 (0.003, 0.187)*		
	T3	ref.	0.125 (0.038, 0.212)*	0.088 (0.001, 0.176)*	ref.	0.036 (-0.056, 0.128)		
Ln(SDNN)	T1	ref.	0.042 (-0.010, 0.095)	0.065 (0.012, 0.118)*	ref.	-0.027 (-0.084, 0.029)		
	T2	ref.	-0.537 (-0.589, -0.484)*	-0.480 (-0.533, -0.427)*	ref.	-0.061 (-0.118, -0.004)*	0.578	0.274
	T3	ref.	0.001 (-0.051, 0.054)	0.001 (-0.051, 0.054)		-0.004 (-0.061, 0.052)		
Ln(RMSSD)	T1	ref.	-0.028 (-0.099, 0.043)	-0.038 (-0.110, 0.033)	ref.	0.005 (-0.072, 0.082)	0.664	0.289
	T2	ref.	-0.927 (-0.999, -0.856)*	-0.843 (-0.914, -0.771)*	ref.	-0.090 (-1.167, -0.013)*		

T3	ref.	-0.259 (-0.330, -0.188)*	-0.232 (-0.304, -0.160)*	ref.	-0.032 (-0.109, 0.045)

[a]Time period refers to the moment when the HRV parameters were measured. Time=1 (T1): pre-exposure; Time=2 (T2): during exposure; Time=3 (T3): post-exposure (see Figure 1)

Models adjusted by: age, gender, body mass index (BMI), and days of the week (see Table S2 – Supplementary Material).

[b]The goodness-of-fit of this model has been assessed with the conditional and marginal R^2, which are concerned with the variance of the fixed effects, and the fixed effects plus the random effects, respectively (Nakagawa and Schielzeth, 2013).

*Statistically significant (p-value≤0.05)