The effect of the visual exercise environment on the response to psychological stress: a pilot study

Carly Wood[a]*, M. Flynn[b], R. Law[b], J. Naufahu[c] and N. Smyth[b]

[a]*School of Sport, Rehabilitation and Exercise Sciences, University of Essex, United Kingdom;*

[b]*School of Social Sciences, University of Westminster, London, United Kingdom*

[c]*School of Life Sciences, University of Westminster, London, United Kingdom*

**corresponding author: Carly Wood, School of Sport, Rehabilitation and Exercise Sciences, University of Essex, Wivenhoe Park, Colchester, CO43SQ; cjwood@essex.ac.uk*

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Background: Performing physical activity whilst exposed to nature can improve health. However, there is little evidence of its impact on stress outcomes. The aim of this study was to examine the influence of the visual exercise environment on the response to a psychosocial stressor. Methods: Eighteen participants were randomised to one of three conditions: i. control; ii. Nature or; iii. Built condition. Participants exercised for 30min on a treadmill at 50% of their VO_2max whilst viewing a video of either a natural or built environment or a blank screen. Following the exercise, participants completed the Trier Social Stress Test (TSST), a standardised laboratory stressor. Salivary samples were collected before, during and after the TSST to calculate cortisol reactivity and recovery. Results: One-way ANOVA revealed a significant effect of viewing condition on cortisol reactivity [$F_{(2, 11)} = 4.686$, $p = .034$; $n^2_p = .460$]; with significantly lower reactivity in the built compared to the nature condition ($p = .027$, $d=1.73$). There was no effect of condition on cortisol recovery ($P>0.05$; $n^2_p = .257$). Conclusions: In the context of the adverse health impact of lower (i.e. blunted) cortisol responding, these findings could indicate a negative impact of the built environment on stress responses.

Keywords: physical activity; green exercise; stress; health

Introduction

Physiological stress can be examined via measurement of cortisol. During stress, two of the body's main physiological stress response systems, the hypothalamic-pituitary-adrenal (HPA) axis and autonomic nervous system (ANS), are activated resulting in cortisol secretion (Dickerson & Kemeny, 2004). Short-term activation of both the HPA axis and ANS due to stress is adaptive and essential for normal functioning; however, repeated activation can lead to cortisol dysregulation and poor stress recovery, both of which are related to physical and psychological ill-health (Acharya, Joseph, Kannathal, Lim & Suri, 2006; Barton, Bragg, Wood & Pretty, 2016; Geisler, Vennewalk, Kubiak &

Weber, 2010; Kyrou & Tsigos, 2009; McEwen, 2013; Stein, Domitrovich, Huikuri & Kleiger, 2005; Turner et al., 2020).

Exposure to nature has been demonstrated to provide positive health outcomes. There is an increasing body of evidence suggesting that direct contact with natural places (including urban nature) improves self-esteem and mood, fosters mental wellbeing and encourages physical activity (PA); all of which can reduce stress (Barton et al, 2016; Bowler, Buyung-Ali, Knight & Pullin, 2010; Lee et al., 2011; Pretty et al., 2007; Thompson Coon et al., 2011; Wood, Pretty & Griffin, 2015). Research suggests that simply viewing a natural environment results in reductions in salivary cortisol, whilst people living in neighbourhoods with more greenspace have healthier cortisol profiles than those living in neighbourhoods with little greenspace (Roe et al., 2013; Thompson et al., 2012). Furthermore, recent research by Hunter, Gillespie & Chen (2019) demonstrated that a nature experience resulted in a 21.3%/hour drop in cortisol beyond the diurnal drop of 11.7%/hour; with the greatest benefits occurring for experiences lasting between 20-30minutes.

PA is also a remedy for many stress related illnesses (Klaperski, et al., 2013; 2014; Pasco et al., 2011; Penedo & Dahn, 2005; Reed & Buck, 2009; Thompson et al., 2012; Warburton, Nicol & Bredin, 2006). Research has identified that individuals who are more physically active have improved cortisol profiles and reduced physiological responses to stressors (Klaperski et al, 2013, 2014; Wood, Clow, Hucklebridge, Law & Smyth, 2018). The cross-stressor adaptation hypothesis suggests that these improved stress responses occur due to biological adaptations which result from regular PA (Klaperski et al., 2014).

Being physically active whilst exposed to natural environments (Green Exercise; GE) provides additive benefits for wellbeing above PA or nature contact alone (Barton & Pretty, 2010; Pretty, Peacock, Sellens & Griffin, 2005; Pretty et al., 2007; Wood et al., 2015; Rogerson et al., 2020). These benefits are derived from all types of natural spaces, exercise intensities and as little as five minutes of engagement (Barton & Pretty, 2010). However, despite the growing evidence for the benefits of GE, there is little evidence of its direct impact on stress outcomes. One such study examined the impact of GE on stress recovery and found that engaging in GE following a stressor was more effective at aiding physiological stress recovery than reading indoors (Van den Berg & Custers, 2011). This was supported by Gladwell, Kuoppa, Tarvainen & Rogerson (2016), who found that a lunch time GE walk resulted in greater heart rate variability during sleep, (defined as the time between adjacent heart beats), and therefore recovery, than a walk in a non-natural environment. However, research has not examined the impact of partaking in GE immediately prior to a stressor. Wood et al (2018) did reveal that a 30-minute moderate intensity walk resulted in lower salivary cortisol levels following a psychosocial stressor (the group version of the Trier Social Stress Test: (TSST)) compared to individuals who did no PA; but the walk included both natural and non-natural environments and did not isolate the impact of the natural environment. Furthermore, the impact of contrasting exercise environments was not examined, and the intensity of exercise was not specific to the participants' individual fitness levels. Given the negative impact of high stress reactivity on health outcomes (Dickerson & Kemeny, 2004; Lundberg, 2005; Smyth, Hucklebridge, Thorn, Evans & Clow, 2013), strategies for reducing responses to stress are of importance. The aim of this pilot study was therefore to examine the influence of the visual exercise environment on the response to a psychosocial stressor. It was hypothesised that there would be differences in stress reactivity and recovery, measured via salivary cortisol and self-report measures of stress, between different environmental viewing conditions.

Methodology

Participants

Eighteen participants took part in the study, including eight males and ten females; with an average age of 32.2±8.5years. Participants were recruited through emails to university staff and students, posters placed around the university, social media posts and word of mouth. To take part in the study participants were required to be between the ages of 18 and 50 years, moderately physically active, free from physical and mental ill health, and fit to take part in PA. Fitness to take part in PA was determined through use of the PA readiness questionnaire (Canadian Society for Exercise Physiology, 1994); for inclusion in the study participants were required to answer 'no' to all questions.

Participant's habitual PA levels were determined via the international PA questionnaire short form, which asks about their vigorous, moderate and walking activities in the last seven days and the time spent in each intensity of PA (Craig et al., 2003). Participants were deemed to be moderately active if they engaged in: i. three or more days of vigorous intensity activity of at least 20minutes; ii. five or more days of moderate intensity PA and/or walking of at least 30minutes; iii. a combination of vigorous, moderate and walking activities achieving a minimum total of at least 600 Metabolic Equivalent of Task (MET) minutes per week. The total MET minutes was determined by the following calculation:

[(Vigorous intensity days X vigorous intensity minutes X 8.0METS) + (moderate intensity days X moderate intensity minutes X 4.0METS) + (walking days X walking minutes X 3.3METS)].

All participants provided individual consent to take part in the study, with institutional ethical approval provided by the University ethics committee. Participants were free to withdraw at any time, without giving reason.

Procedures

Participants were requested to attend the university laboratory on two occasions (see Figure 1). On the first visit participants had demographic information collected and had their height and weight assessed for the calculation of body mass index. An online questionnaire was also completed to assess trait health and behavioural outcomes. This included assessment of wellbeing, perceived stress, beliefs about GE and frequency of nature exposure and GE participation. Participants were next fitted with a Polar heart rate monitor (Polar Electro N2965, China) and asked to perform a warm up. The warm up consisted of 2.5 minutes self-selected treadmill walking or jogging, followed by a further 2.5 minutes of self-guided stretching. Following the warm-up participants were asked to take part in a VO_2max test on the treadmill, whereby they were required to run until volitional exhaustion (see VO_2max section below for full details). Throughout the test participants' expired gases were examined using a cortex analyser (Metalyzer 3B-R3 Cortex Biophysik GmbH, Germany), along with ratings of perceived exertion (Borg, 1982) and heart rate. These measures were used to determine the participant's maximum oxygen consumption. Immediately following the VO_2max test participants cooled down on the treadmill for a further 2.5 minutes followed by 2.5 minutes of stretches.

The second visit to the university took place at least one week after the VO_2max test. Participants were required to exercise on the treadmill for 30 minutes at the speed at which they had previously reached 50% of their VO_2max. During this exercise, participants were randomly allocated to one of three viewing conditions: i. nature video;

ii. built environment video and; iii. control. Participants watched their allocated video (or faced a blank screen) for the duration of the exercise and had no engagement with the researchers during this time. Before and after the exercise participants completed the warm up and cool down procedures followed during the VO_2max test session.

Immediately following the exercise, participants took part in the Trier Social Stress Test (Kirschbaum, Pirke & Hellhammer, 1993) (see below for full details). Salivary cortisol samples were collected before the exercise and throughout the stress testing period; whilst the Stress-Arousal Checklist (SACL; Mackay, Cox, Burrows & Lazzerini, 1978) was completed before the exercise and before and after the stress test. At this time participants were also asked to rate the ease, intrusiveness, enjoyment and comfort of the exercise intervention on a scale from one to seven; with a higher score indicating more enjoyment and comfort and less intrusion and difficulty. A mean score for all four variables was also calculated to provide an overall rating of the intervention, a higher score indicated a better experience.

VO_2max Test

Prior to taking part in the VO_2max test Polar heart rate monitors were attached to the participants (Polar Electro N2965) to allow continuous monitoring of heart rate. Following the warm up, participants were fitted with a face mask (Vmask Hans Rudolph, USA), which was attached to their face using a mesh head harness. The mouth piece on the mask was attached to a cortex analyser (Metalyzer 3BR3 Cortex Biophysik GmbH Germany) to allow continuous monitoring of pulmonary gas exchange throughout the test. The starting speed for the VO_2max test ranged from 6-7km/h, depending on the participants' prior experience; and increased by 1km/h after each minute of the test. On completion of each minute of the test oxygen uptake, rating of perceived exertion (Borg, 1982) and heart rate were recorded. Participants were verbally encouraged to continue for as long as possible and until they felt they could no longer continue. When the participants could not proceed with the test they were asked to jump to the sides of the treadmill. The participants' maximal oxygen uptake (VO_2max; mL.kg-min) was calculated by taking the average oxygen uptake from the last 30 seconds of the test.

Exercise Intervention

At least one week following the VO_2max test participants exercised on the treadmill for 30 minutes at 50% of the speed at which they reached their maximal oxygen uptake (average speed 7.4±0.8km/h). During the exercise participants were randomly allocated to one of three environmental viewing conditions through the selection of a piece of paper numbered with either a one, two or three. These numbers corresponded to allocation to either a: i. nature video; ii. built environment video or; iii. Control. In the nature condition, the video consisted of scenes extracted from "Evening Run through Endless Forest"; whilst in the built condition, the video consisted of scenes extracted from the "Boston Marathon Route" (videos produced by Outside Interactive, Hopkinton, MA, USA). These videos were previously used in the study of Rogerson & Barton (2015). In the control condition participants exercised whilst viewing a blank screen. Immediately prior to the exercise participants also rested for ten minutes, after which the first salivary cortisol sample was collected (sample 1).

Stress Test

Following the exercise participants took part in the Trier Social Stress Test (TSST) (Kirschbaum et al., 1993). The TSST comprises uncontrollability and socio-evaluative threat known to reliably activate the HPA axis (Dickerson and Kemeny, 2004). The TSST included three main phases: i) the preparatory period (15 minutes); ii) the stress task period (12 minutes) and; iii) a resting and debriefing period (40 minutes). During the preparatory period participants were briefed on the stress test procedures and given 5-minutes of quiet time to prepare notes for a mock job interview where they were asked to prepare a 5-minute speech as if applying for a job in their field and to introduce themselves to the committee. On completion of these preparation tasks participants were asked to provide a second saliva sample (sample 2).

During the TSST participants were moved into an additional room and were instructed to stand in front of a seated committee consisting of one man and one woman. The committee were wearing white laboratory coats. There were also two video cameras pointing at the participants. A committee member asked each participant to make their five-minute speech. Standard responses were given by the committee when participants ended their speech early ("you still have time remaining please continue"). On completion of the speech (5 minutes) the third saliva sample (sample 3) was collected.

The committee then asked the participants to serially subtract 17 from a given number as fast and accurately as possible for 5 minutes. If participants failed in the subtraction task, standard responses were employed ("you have made a mistake please start again from the number…"). Following the arithmetic task saliva sample four was collected. Immediately after completion of the TSST participants returned to the preparation room. Participants provided saliva samples every 10 minutes up to 40 minutes (samples 5-8). During this time, they were also debriefed on the study.

Stress Measures

Salivary Cortisol

Cortisol was measured in saliva samples collected through use of salivettes (Sarstedt Ltd., Leicester, UK). In all participants, samples were collected before the exercise (sample 1), prior to the TSST (sample 2); immediately after the public speaking task (sample 3), after the mental arithmetic task (sample 4); and every 10 mins up to 40 mins (sample 5-8). In line with best practice guidelines testing commenced in the afternoon to control for changes in basal cortisol secretion in the morning and following the post-prandial period (Dockray, Susman & Dorn, 2009; Smyth et al., 2013). Participants refrained from food, caffeine and smoking during the testing period. All saliva samples were frozen at -20°C until assayed. Samples were thawed and then centrifuged for 10 minutes at a speed of 3500 rpm. Cortisol concentrations were determined in duplicates at the Psychophysiology and Stress Research Group's laboratory at the University and were established by enzyme-linked-immunosorbent assaying, developed by Salimetrics LLC (State College, PA). Intra- and inter-assay variations were both <10%.

Stress and Arousal

Stress was also assessed using the Stress Arousal Checklist (SACL; Mackay et al, 1978). The SACL is a 30-item scale whereby participants are asked to rate how they are feeling in a given moment by selecting either 'definitely', 'slightly', 'uncertain', or 'not' to a list of 30 words reflecting either stress or arousal. Positively worded stress items (e.g peaceful) were recoded so that a score of zero was awarded when participants indicated they were 'definitely' or 'slightly' experiencing the stress state and a score of one was awarded when participants were 'uncertain' or 'not' experiencing the stress state. For negatively worded stress items (e.g worried) a score of zero was awarded when participants indicated they were 'uncertain' or 'not' experiencing the stress state; whilst a score of one was awarded when the participant was 'definitely' or 'slightly' experiencing the stress state. A mean score was then calculated to reflect overall stress. The score ranged from zero to one, with a score of one reflecting the highest possible experience of stress.

Arousal scores were also recoded. For positively worded arousal items (e.g. active) a score of zero was awarded when participants indicated they were ‘uncertain’ or ‘not’ experiencing the arousal state and a score of one was awarded when participants were ‘definitely’ or ‘slightly’ experiencing the arousal state. For negatively worded arousal items (e.g. sluggish) a score of zero was awarded when participants indicated they were ‘definitely’ or ‘slightly’ experiencing the arousal state; whilst a score of one was awarded when the participant was ‘uncertain’ or ‘not’ experiencing the arousal. A mean score was then calculated to reflect overall arousal. The score ranged from zero to one, with a score of one reflecting the highest possible level of arousal. The questionnaire was completed prior to the exercise intervention and stress test and immediately following the stress test.

Trait Measures

In addition to measures of stress and arousal, participants completed an online questionnaire examining trait health and behavioural measures. The online questionnaire included the Warwick Edinburgh Mental Wellbeing Scale (Tennant et al., 2007), the Perceived Stress Scale (Cohen, Kamarck & Mermelstein, 1983), the Intentional Nature Exposure scale (Wood, Barron & Smyth, 2019) and the Beliefs about GE scale (Flowers, Freeman & Gladwell, 2017).

Warwick Edinburgh Mental Wellbeing Scale (WEMWBS)

The WEMWBS is a 14-item positively worded scale which monitors wellbeing in the general population (Tennant et al., 2007). The scale has five response categories from one (none of the time) to five (all of the time) which are summed to give a score between 14-70; with a higher score representing a better wellbeing. The scale has a Cronbach alpha score of 0.90 (Tennant et al., 2007) and in the current sample had an alpha of 0.90, indicating very good reliability. The scale was used to ask participants to rate their wellbeing over the last month.

Perceived Stress Scale (PSS)

Stress was assessed using the 10-item PSS (Cohen et al., 1983). The scale measures an individual's appraisal of the degree to which situations in his or her life are stressful. All items were rated on a five-point scale from zero (never) to four (very often). Four items were reverse scored and an overall score between 0-40 was computed, with higher scores reflecting greater stress. The PSS has previously been demonstrated to have a Cronbach alpha ranging from .78-.91. In the current sample the alpha was .83, indicating very good reliability.

Intentional Nature Exposure Scale

The Intentional Nature Exposure Scale is a five-item scale which assesses overall exposure to nature and GE, including every day and non-everyday environments (Wood et al., 2019). Each question on the scale was scored on a 5-point likert scale (1 = *high/a great deal*, 5 = *low/not much*), with higher scores reflecting greater nature exposure and participation in GE. The scale has previously been demonstrated to have an alpha of 0.84 and in the current sample had an alpha of .89; indicating very good reliability (Wood et al., 2019).

Beliefs about Green Exercise

The beliefs about GE questionnaire consists of 17 multiple choice questions about participants GE beliefs, scored on a scale from one to seven (Flowers et al., 2017). Seven items are reversed scored, and then item scores averaged to determine the intention subscale (5 items), attitude subscale (6 items), subjective norm subscale (3 items) and the perceived behavioural control subscale (3 items). A higher score on each subscale indicates a more positive attitude and greater intention to partake in GE and greater perceived control.

Treatment of Data and Statistical Analysis

One-way analysis of variance (ANOVA) was conducted to compare demographic and trait psychometric variables between the three viewing conditions; whilst a Kruskall-Wallis was used to compare the overall intervention experience and its difficulty, intrusion, comfort and enjoyment. As is common, cortisol values were moderately skewed. To normalize data a square root transformation was performed (see Smyth et al., 2013; von Dawans, Kirschbaum & Heinrichs, 2011) prior to statistical analyses. However, for illustration purposes untransformed values are presented in the tables and figures. A repeated-measures ANOVA was conducted to examine differences in cortisol over time. Within-subjects contrasts were used to assess the pattern of cortisol secretion. Cortisol stress reactivity was calculated as the increase from the baseline sample, measured immediately prior to the TSST (sample 2), and participant's' individual peak sample (Miller et al., 2018). Cortisol recovery was calculated as the participant's individual peak sample minus the final sample (sample 8). In line with the recommendations of Miller et al (2013) non-responders were identified as participants that did not exhibit an increase of cortisol > 1 nmol/l. We therefore excluded four participants (22%) who were classified as non-responders. Two were from the control condition and two were from the nature condition; one male and one female in each condition. This non-responding rate is lower than previous studies which have demonstrated non-responding rates of 60-65% (Smyth et al., 2019; Steptoe, Hamer, Lin, Blackburn & Erusalimsky, 2017, Hamer and Steptoe 2012). Following removal, one-way ANOVA was used to compare the cortisol composites between the three viewing conditions.

One-way ANOVA also compared pre-exercise stress and arousal scores between the exercise groups. Stress and arousal change scores were generated by computing the difference between stress and arousal from pre- exercise to pre- stress test and pre-post stress test. One-way ANOVA was then used to compare the change in scores between the viewing conditions. Pearson's correlation examined the relationship between cortisol composites and stress-arousal scores. Statistical analysis was conducted using SPSS (v.24), with significance set at a P value of 0.05.

Results

Participants

Demographic data are presented in Table 1. One-way between subject's ANOVA revealed no significant differences between participants in the three viewing conditions in terms of age, BMI, VO_2max, intentional nature exposure, wellbeing, their beliefs about GE or perceived stress ($p>0.05$). There were also no differences in pre- exercise and pre-TSST salivary cortisol concentrations, or pre-exercise self-reported stress and arousal.

Effect of Exercise Environment on Stress Response Systems

Cortisol reactivity and recovery

Raw values for cortisol concentrations ranged from 0.4nmol/l to 31.91 nmol/l. One way within ANOVA revealed that the TSST-G induced an overall cortisol response in all participants [$F_{(2.0,34.4)} = 29.552$, $p < 0.001$; $n^2_p = .635$] (see Figure 2). Within-subjects contrasts revealed a significant quadratic effect [$F_{(1,17)} = 13.951$, $p < 0.01$; $n^2_p = .451$], such that on average cortisol increased from baseline, peaking at the fifth sampling point (20 min after the completion of the TSST) and declining thereafter.

Following removal of non-responders, a one-way ANOVA revealed a significant main effect of viewing condition on cortisol reactivity [$F_{(2, 11)} = 4.686$, p = .034; n^2_p= .460]; with significant differences between the nature and built conditions (p = .027, *d*=1.73). Participants in the built condition exhibited significantly lower cortisol reactivity compared to participants in the nature condition, see Figure 3. There were no significant differences in cortisol reactivity between the control condition and the built (P>.05; *d*=.84*)* or the control and nature conditions (p> .05; *d*=.83). A one-way ANOVA also revealed no significant differences in cortisol recovery between groups (p >.05; n^2_p= .257) (Table 2).

Stress and Arousal

There were no significant differences in pre-exercise stress and arousal scores between participants in the three conditions (p>.05; Table 2). A one-way ANOVA revealed a significant effect of viewing condition on the change in stress between pre-exercise and pre-stress test (F(2,17) = 5.325; p=.018; n^2_p= .415); with a greater increase in stress in the built condition compared to the nature condition (P=.014; *d*=2.26); but no significant differences between the built and control (p>.05; *d*=1.10) or the nature and control (p>.05; *d*=.70). There were no significant differences between viewing conditions in the change in arousal between pre-exercise and pre-stress test (p>.05; *d=.07*) or the change in stress (p>.05; *d*=.10) and arousal (p>.05; *d*=.01) pre-post stress test.

Association between cortisol composites and self-reported stress

Pearson's correlations revealed that cortisol reactivity in the cortisol responders was significantly negatively correlated to stress immediately prior to the TSST (r=-.547; p=.043). There were no significant correlations with scores before the exercise or after the TSST and no significant correlations with arousal at any of the three time points ($p>.05$). Higher reports of stress before the TSST were associated with less cortisol reactivity.

Experience of the Intervention

A Kruskal-Wallis test revealed no significant effect of the viewing environment on the difficulty ($p>.05$; $n^2_H= .024$), intrusiveness ($p>.05$; $n^2_H= .069$), enjoyment ($p>.05$; $n^2_H= .103$) or comfort of the intervention ($p>.05$; $n^2_H= .238$). There was also no effect of the exercise environment on the overall experience score ($p>.05$; $n^2_H= .157$). Participants in the nature group reported the intervention was most enjoyable and comfortable and least difficult (Table 3). These participants also reported a better overall experience than those in the built and control condition, with the control condition participants reporting the worst experience.

Discussion

The aim of this pilot study was to examine the influence of the visual exercise environment on the response to a psychosocial stressor. The findings revealed that there was a significant effect of the visual exercise environment on cortisol reactivity, but not recovery; with participants in the built condition having significantly lower (i.e. blunted) stress reactivity than participants in the nature condition. There were no significant differences between participants in the control condition and the nature or built conditions, however the control group exhibited a larger response than participants in the built condition. To date, there are no known studies examining the influence of different exercise environments immediately prior to a stressor on stress reactivity. The authors of the current study did previously identify that a 30-minute moderate intensity walk in a green area via an urban area immediately prior to the TSST resulted in significantly reduced overall cortisol levels when compared to no physical activity (Wood et al., 2018); however, the possible effect of the exercise environment was not examined.

Although higher cortisol stress reactivity has been associated with poorer health outcomes; recent studies have also demonstrated that lower (i.e. blunted) cortisol responding, represented by a smaller increase in cortisol from baseline to peak, is just as indicative of poor health (Caroll, Ginty, Whittaker, Lovallo & de Rooij, 2017; Oskis, Smyth, Flynn & Clow, 2019; Smyth et al., 2019; Turner et al., 2020). In fact, larger cortisol reactivity might be protective against stress-related depression, with evidence suggesting that individuals suffering from clinical depression might have blunted cortisol stress reactivity and impaired recovery (Burke, Davis, Otte & Mohr, 2005). Blunted responding to a psychosocial stressor is predictive of poorer physical and mental health later on in life, as shown by prospective studies (Turner et al., 2020). The lower cortisol reactivity in the built group when compared to both the nature and control condition (but only significantly different for the nature environment) might therefore be indicative of a negative impact of the built exercise environment on stress reactivity. Previous GE research by Pretty et al (2005) revealed that exercise whilst viewing a built environment reduced the positive effects of exercise on self-esteem when compared to exercise when viewing natural environments or exercise alone. If we consider the findings of this research in the context of lower (i.e. blunted) cortisol responding, a similar effect is identified; whereby exercising in built environments has adverse effects on cortisol reactivity. The exact mechanisms for this potential effect are unclear, but one possible explanation is focused around the effect of different environments on mental fatigue and attention. According to the attention restoration theory (Kaplan and Kaplan, 1989); natural environments are restorative and can therefore reduce mental fatigue and improve attention. By contrast, built environments can contribute to mental fatigue and result in reduced attentional capacity (Hartig, Evans, Jamner, David & Garling, 2003). Given that the TSST requires focused attention and that mental fatigue can impair emotional regulation (Grillon, Quispe-Escudero, Mathur & Ernst, 2015); it is possible that the blunted cortisol reactivity in the built environment group resulted from a reduced capacity to regulate emotions. However, this idea is speculative and further research would be required to assess mental fatigue, emotional regulation and cortisol reactivity following exposure to different environments.

In addition to the reduced cortisol reactivity, participants in the built environment condition experienced a significantly greater increase in self-reported state stress from pre-exercise to pre-stress test compared to the nature viewing condition. This finding is supported by the significant negative relationship between stress reactivity and self-reported stress prior to the TSST; with the most stressed participants (according to the SACL) having the least cortisol reactivity. The nature viewing condition resulted in the smallest increases in self-reported state stress; in support of the growing body of evidence suggesting a beneficial impact of GE on self-reported health outcomes (Barton & Pretty, 2010; Pretty et al., 2005, 2007; Rogerson, Brown, Sandercock, Wooller & Barton, 2015; Wood et al., 2015).

Participants in the nature viewing condition also reported that their experience of the exercise was most enjoyable and comfortable and least difficult; with an overall better experience. Although these findings were not significant, they could be indicative of a role of GE in influencing exercise adherence. In fact, previous research has demonstrated that participants experience greater enjoyment and intention for future exercise participation when exercising in an outdoor natural environment compared to either an indoor or built environment (LaCaille, Masters & Heath, 2004; Focht, 2009).

Given the low levels of PA in adults (British Heart Foundation, 2015); strategies for increasing participation are essential and these relationships therefore warrant further investigation

The current study was a well-controlled and intensive pilot study which rigorously controlled exercise intensity according to individual fitness levels and included a control group who exercised in front of a blank screen. However, there are some limitations that require consideration. Firstly, due to the intensive nature of this pilot study, there were only a small number of participants in each exercise group. The study therefore needs to be replicated on a larger scale to confirm that the same trend of results in a larger population. Furthermore, participants were moderately active and had higher than average fitness. The average VO_2max for males and females was 39.1ml.kg.min^{-1} and 48.0ml.kg.min^{-1} respectively, representing above average fitness in both groups (Riebe, Ehrman, Liguori, & Magal, 2017). Given the positive impact of both fitness and habitual PA on stress outcomes (Klaperski et al., 2013; 2014); it is therefore not possible to generalise these results to the wider population and inactive groups. Future research should therefore incorporate participants from a variety of PA and fitness groups to ensure that the findings are applicable to a wider audience.

The use of 'artificial' exercise environments is also a key study limitation; as the multi-sensory experience (i.e. nature sights, sounds and smells) of exercising in a natural environment was unlikely to have been felt by participants. However, the laboratory environment enables the exercise characteristics to be rigorously controlled, not just in terms of exercise intensity, but also factors such as temperature and humidity which could influence exercise outcomes. This approach is therefore essential to demonstrating the principle of the GE effect and has been utilised in other published studies (Pretty et al., 2007; Rogerson & Barton, 2015). It should also be noted that there are several groups in society who may be unable to access 'real' natural environments and for whom artificially stimulated natural environments might be important, for example those who are in highly urbanised areas with no nature access or confined indoor settings. Further consideration of how the full sensory experience of nature can be created indoors, for example through use of virtual reality software, is therefore essential to furthering research in this field and exploring the findings of this research more widely.

Overall the findings of this well controlled and intensive pilot study where participants exercise was matched to their fitness level, revealed differences in cortisol reactivity to a psychosocial stressor between those viewing natural and built environments. Participants in the built condition had significantly reduced cortisol stress reactivity and greater increases in self-reported stress than participants who took part in a natural environment viewing condition. There were also significant negative relationships between cortisol reactivity and self-reported stress. In the context of the negative health impact of blunted cortisol responding, these findings could indicate a negative impact of the built exercise environment on stress responses and an undoing of the positive effects of exercise. Additional and larger scale studies are required to explore and confirm these concepts further.

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Table 1. Descriptive statistics for demographic and trait health measures for participants in the three exercise conditions.

	Nature Condition	Built Condition	Control	Total
N (%)				
Gender - Male N (%)	3 (50)	2 (33)	3 (50)	8 (44)
Ethnicity – white N (%)	5 (83)	5 (83)	4 (67)	14 (78)
Employment Status – full time N (%)	4 (67)	2 (33)	4 (67)	10 (56)
Female Luteal Menstrual Phase N (%)	2 (67)	2 (66)	1 (33)	5 (55%)
M (SD)				
Age (yrs)	33.2±9.2	32.5±9.1	30.8±8.8	32.2±8.5
BMI (kg.m^2)	24.6±2.8	21.5±3.1	24.3±3.8	23.5±3.4
VO_2max (ml.kg.min^{-1})	42.3±13.6	44.5±7.8	42.3±5.7	43.1±9.1
Nature exposure and GE	18.2±5.6	19.2±3.5	22.0±3.2	19.8±4.3
GE intention	5.4±1.3	4.9±2.0	5.8±0.8	5.4±1.4
GE attitude	6.3±1.0	5.9±1.4	6.6±0.4	6.3±1.0
GE subjective norm	3.8±1.3	4.3±0.7	4.9±1.3	4.4±1.1
GE perceived behavioural control	5.5±1.1	5.7±1.4	5.6±0.9	5.6±1.1
Wellbeing	51.7±9.2	52.3±4.5	52.5±8.5	52.2±7.2
Perceived stress	21.2±1.2	20.7±2.8	20.8±1.5	20.9±1.8

GE= Green Exercise

Table 2. Cortisol and Stress-Arousal Checklist variables for participants in the three exercise conditions.

	Nature Condition	Built Condition	Control
Cortisol Reactivity (nmol)	15.90±7.18	6.43±2.97*	10.85±4.30
Cortisol Recovery (nmol)	3.80±4.00	2.31±1.72	2.42±2.85
Change in stress pre-exercise to pre TSST	0.06±0.13	0.42±0.19*	0.20±0.24
Change in arousal pre-exercise to pre TSST	-0.05±0.20	-0.02±0.19	0.08±0.28
Change in stress pre-post TSST	-0.03±0.27	-0.26±0.42	-0.20±0.26
Change in arousal pre-post TSST	-0.10±-0.23	-0.12±0.19	-0.08±0.17

*indicates a significant difference between nature and built condition; SACL data includes cortisol non-responders

Table 3. Participant experience of the exercise interventions

	Nature Condition	Built Condition	Control
Difficulty	6.2±1.3	6.0±1.2	5.0±1.8
Intrusiveness	1.8±1.3	2.0±1.2	2.8±1.9
Enjoyment	5.0±1.0	4.0±1.2	3.7±1.4
Comfort	6.2±0.8	5.2±1.9	4.2±1.5
Overall experience	4.8±0.7	4.3±0.6	3.9±0.7

Note: A higher score indicates less difficulty and intrusiveness, more enjoyment and comfort and a better overall experience.

Figure 1. Study timeline

Figure 2. Mean±SEM Cortisol response to the TSST in all participants (n=18).

Figure 3. Mean±SEM cortisol reactivity in the three exercise conditions (n=14) (* indicates a significant difference between the nature and built exercise condition; P=0.027).