More green space is linked to less stress in deprived communities: Evidence from salivary cortisol patterns

Catharine Ward Thompson [a,*], Jenny Roe [b,1], Peter Aspinall [b,2], Richard Mitchell [c,3], Angela Clow [d,4], David Miller [e,5]

[a] OPENspace Research Centre, University of Edinburgh, Lauriston Place, Edinburgh EH3 9DF, UK
[b] OPENspace, School of the Built Environment, Heriot-Watt University, Edinburgh EH14 4AS, UK
[c] Centre for Research on Environment, Society and Health, College of Medical, Veterinary and Life Sciences, University of Glasgow, 1 Lilybank Gardens, Glasgow G12 8RZ, UK
[d] Department of Psychology, University of Westminster, 309 Regent Street, London W1B 2UW, UK
[e] The James Hutton Institute, Craigiebuckler, Aberdeen AB15 8QH, UK

ARTICLE INFO

ABSTRACT

Green space has been associated with a wide range of health benefits, including stress reduction, but much pertinent evidence has relied on self-reported health indicators or experiments in artificially controlled environmental conditions. Little research has been reported using ecologically valid objective measures with participants in their everyday, residential settings. This paper describes the results of an exploratory study ($n = 25$) to establish whether salivary cortisol can act as a biomarker for variation in stress levels which may be associated with varying levels of exposure to green spaces, and whether recruitment and adherence to the required, unsupervised, salivary cortisol sampling protocol within the domestic setting could be achieved in a highly deprived urban population. Self-reported measures of stress and general wellbeing were also captured, allowing exploration of relationships between cortisol, wellbeing and exposure to green space close to home. Results indicate significant relationships between self-reported stress ($P < 0.01$), diurnal patterns of cortisol secretion ($P < 0.05$), and quantity of green space in the living environment. Regression analysis indicates percentage of green space in the living environment is a significant ($P < 0.05$) and independent predictor of the circadian cortisol cycle, in addition to self-reported physical activity ($P < 0.02$). Results also show that compliance with the study protocol was good. We conclude that salivary cortisol measurement offers considerable potential for exploring relationships between wellbeing and green space and discuss how this ecologically valid methodology can be developed to confirm and extend findings in deprived city areas to illuminate why provision of green space close to home might enhance health.

1. Introduction

There is an expanding body of research exploring the relationship between green space and health, from national level epidemiological studies (de Vries, Verheij, Groenewegen, & Spreeuwenberg, 2003; Maas, Verheij, Groenewegen, de Vries, & Spreeuwenberg, 2006; Mitchell & Popham, 2007, 2008; van den Berg, Maas, Verheij, & Groenewegen, 2010) to very localised case studies (Grahn, Ivarsson, Stigsdotter, & Bengtsson, 2010) and experimental studies (Hartig, Evans, Jamner, Davies, & Gärling, 2003; Hartig, Mang, & Evans, 1991; Park et al., 2007; Park, Tsunetsugu, Kasetani, Kagawa, & Miyazaki, 2010; van den Berg & Custers, 2011; van den Berg, Koole, & van der Wulp, 2003). There is evidence for a positive relationship between access to green or natural environments and people's perceived overall general health (de Vries et al., 2003; Maas et al., 2006), mental health (Grahn & Stigsdotter, 2003; Hartig et al., 2003; Maas, Verheij, et al., 2009; Ottosson & Grahn, 2005), longevity (Takano, Nakamura, & Watanabe, 2002), physical health (Coombes, Jones, & Hillsdon, 2010; Humpel, Owen, & Leslie, 2002) and social health (de Vries, 2010; Kim & Kaplan, 2004; Kweon, Sullivan, & Wiley, 1998; Maas, van Dillen, Verheij, & Groenewegen, 2009; Sullivan, Kuo, & Depooter, 2004). From epidemiological studies based in urban settings, these relationships appear to be stronger among deprived populations (Mitchell & Popham, 2008).

* Corresponding author. Tel.: +44 131 221 6176/6177; fax: +44 131 221 6157.
  E-mail addresses: c.ward-thompson@ed.ac.uk
(C. Ward Thompson), j.roe@hw.ac.uk (J. Roe), p.a.aspinall@hw.ac.uk (P. Aspinall),
Richard.Mitchell@glasgow.ac.uk (R. Mitchell), clowa@westminster.ac.uk (A. Clow),
david.miller@hutton.ac.uk (D. Miller).
  [1] Tel.: +44 131 451 4629.
  [2] Tel.: +44 131 221 6176.
  [3] Tel.: +44 141 330 1663.
  [4] Tel.: +44 207 911 5000x2174.
  [5] Tel.: +44 1224 395000/395276.

The evidence is particularly strong for positive associations between experience of natural environments and mental health. It appears that contact with natural environments promotes psychological restoration (Kaplan & Kaplan, 1989), improved mood (Barton & Pretty, 2010; Hartig et al., 2003; Roe & Aspinall, 2011), improved attention (Hartig et al., 2003; Ottosson & Grahn, 2005) and reduced stress and anxiety (Grahn & Stigsdotter, 2003; Hartig et al., 2003; Maas, Verheij, et al., 2009; Ulrich et al., 1991). Within deprived social housing communities in Chicago, research has consistently shown the benefit of green space both to cognitive restoration (Faber Taylor, Kuo, & Sullivan, 2002; Kuo, 2001), self-discipline (Faber Taylor et al., 2002), reduced aggression (Kuo & Sullivan, 2001a) and reduced crime (Kuo & Sullivan, 2001b).

1.1. Mechanisms by which natural environments might be associated with stress reduction

Understanding the mechanisms by which natural environments contribute to stress reduction or restoration is important if this contribution is to be exploited for public health improvement. There are three candidate behavioural mechanisms which may operate synergistically, depending on the environment and contact type (de Vries, 2010). Firstly, many people undertake some form of physical activity as an inherent part of experiencing natural environments; walking in a park for example. The positive effects on mood and stress of physical activity are well established (Barton & Pretty, 2010; Penedo & Dahn, 2005). Secondly, people frequently have the opportunity for some kind of social contact, however informal or unplanned, when they experience green space; they may go with someone, or engage with others while there. Social contact is also known to have positive effects on mood and stress level (Heinrichs, Baumgartner, Kirschbaum, & Ehlert, 2003). Thirdly, people often deliberately seek environments that they find attractive for relaxing, to allow them to recover from demanding situations and tasks, and natural environments are frequently sought for this purpose (Grahn et al., 2010; Hartig, 2007, 2008; Kaplan, 1995; Kaplan & Kaplan, 1989). In terms of psychological and physiological mechanisms, there is evidence of independent responses that are promoted by the perception of natural environments (Hartig et al., 1991; Ulrich et al., 1991) and which may contribute to people's response to stress and their ability to cope with it (Lee et al., 2011; McEwen & Stellar, 1993; Park et al., 2007, 2010). The principal theoretical model for these responses is Ulrich's psychoevolutionary model (Ulrich, 1983; Ulrich et al., 1991), which proposes a direct impact of perceiving the natural environment on an individual's brain and body. This is thought to take place via psychoneuroendocrine mechanisms, including the functioning of the hypothalamic pituitary adrenal (HPA) axis which regulates cortisol secretion and whose dysregulation is associated with a range of disease outcomes (Li, Power, Kelly, Kirschbaum, & Hertzman, 2007; Tsigos & Chrousos, 2002). If mechanisms such as this are in operation, we should therefore expect to observe a biological impact of contact with natural environments. Experimental studies have confirmed this. Being in or viewing green space has been shown to reduce physiological measures of stress including blood pressure (Hartig et al., 2003; Ulrich et al., 1991), heart rate (Ulrich et al., 1991), skin conductance and muscle tension (Ulrich et al., 1991), although some studies (e.g. Ottosson & Grahn, 2005) have failed to find measurable physiological differences. In Japan, a study exploring the effect of a green space intervention (Shinrin-yoku – taking in the forest atmosphere) has shown that forest environments can promote lower concentrations of cortisol, lower pulse rate, lower blood pressure, greater parasympathetic nerve activity and lower sympathetic nerve activity when compared to city environments (Park et al., 2007, 2010).

1.2. Extending experimental evidence with observational evidence

However, almost all of the work reported above has either been carried out in artificially controlled experimental conditions, whether in the laboratory or in the field, with certain, limited categories of participant (e.g. university students, hospital patients with certain morbidities). While experiments that artificially control exposure to the environment may strengthen the case for a causal relationship between stress reduction and some form of visual or embodied access to green space, they are not easily generalised to a population level. As far as we are aware, no research has attempted to detect a biological impact of exposure to green and natural environments encountered as part of 'everyday life', especially for deprived populations. The observational study reported here was specifically designed to extend the evidence provided by experimental studies, by seeking evidence for the impact of urban green space on biomarkers of stress in the 'real world' of people's normal patterns of activity and experience, for those likely to be experiencing multiple deprivation.

The use of cortisol as a biomarker of stress was selected as it has been shown to be sensitive to activities in natural environments in the studies by Lee et al. (2011) and Park et al. (2007, 2010), taking male university students to forest and city environments away from their usual work or home contexts, and more recently by van den Berg and Custers (2011), who found similar effects by assigning allotment gardeners to experimental tasks before and after time spent gardening or indoor reading. However, these studies involved controlled tasks and environmental conditions, where salivary cortisol levels were measured before and after exposure to different, specified environments. By contrast, our study sought to examine cortisol patterns across the day for people in routine contexts and patterns of behaviour in their everyday environment. We chose diurnal patterns of cortisol as an outcome measure since they offer an ecologically meaningful measure of chronic stress: diurnal cortisol patterns reflect everyday circadian rhythms of health and longer term effects of stressors in the social and physical environment (Li et al., 2007), rather than responses pre and post exposure to a particular environment at a single point in time.

1.3. Patterns of cortisol secretion as a biomarker of chronic stress

Diurnal variation of salivary cortisol was selected as the biomarker of stress in our study since it is a measure that reflects everyday physiological functioning of the HPA axis and is sensitive to a variety of responses to stress (Hsiao et al., 2010; Li et al., 2007). In addition to its key role in responding to acute stressors, cortisol is a vital hormone for orchestrating healthy body functioning around the 24 h circadian cycle (Nader, Chrousos, & Kino, 2010). Disrupted patters of cortisol secretion are indicative of circadian rhythm dysregulation which is associated with poor mental and physical health (Nader et al., 2010; Wulff, Gatti, Wettstein, & Foster, 2010).

The core characteristic of healthy cortisol secretion is that levels are carefully regulated by HPA axis to give very different concentrations at different times of the day. The circadian cycle (with levels changing from a daytime peak that may be as high as 20 nmol/l shortly after awakening to a low of perhaps 1 nmol/l in the early hours of sleep, see Edwards, Clow, Evans, & Hucklebridge, 2001) signals to other body systems when it is night and day. Healthy diurnal patterns of cortisol secretion show such a daytime peak shortly after awakening but a range of conditions are associated with a flattening of the cortisol circadian rhythm, i.e. a less steep decline in levels from morning until evening. In some cases, this flatter slope is associated with increased overall cortisol secretion (a 'high

flat' slope), for example in normal ageing or in clinical depression (Deuschle et al., 1997; Weber et al., 2000), whereas in other conditions the flatter slope is associated with overall reduced levels of cortisol secretion (a 'low flat' slope), for example in post-traumatic stress disorder (PTSD), a combination of PTSD and long term negative life events, repressive anxiety and chronic fatigue (de Kloet et al., 2007; Giese-Davis, Sephton, Abercrombie, Duran, & Spiegel, 2004; Jerjes, Cleare, Wessely, Wood, & Taylor, 2005; Li et al., 2007; Witteveen et al., 2010).

The circadian cycle of cortisol secretion is thus sensitive to the effects of chronic stress (Meerlo, Sgoifo, & Turek, 2002; Nader et al., 2010), affording not only a biomarker of chronic stress but also a mechanism by which stress and health are linked. Disrupted cortisol cycles negatively impact upon a range of other body systems with health related outcomes (Cacioppo et al., 2002; Kyrou & Tsigos, 2009; Sephton, Sapolsky, Kraemer, & Spiegel, 2000; Sherwood Brown, Varghese, & McEwen, 2004; Strickland, Morriss, Wearden, & Deakin, 1998). The circadian cycle, and its variation, thus complicate the use of cortisol as a simple biological marker, but reveal more about stress than simple cortisol concentrations.

1.4. Aims of this study

Our study asked whether, among residents of a deprived urban area, the presence of different amounts of green space in the environment around people's homes was associated with:

a. stress as measured by levels and/or patterns of cortisol secretion over the day; and/or
b. stress and more general wellbeing as measured by self-report scales.

We also wanted to test:

c. the viability of unsupervised collection of saliva samples, within the domestic setting of such a population, at the required times post-awakening; and
d. whether physical activity levels moderate or confound the findings on stress levels.

2. Study design and recruitment of sample

2.1. Study design

The study was located in Dundee, UK. Dundee had a population of 153,226 in 2001 and contains a number of highly deprived neighbourhoods with varying levels of green space. The design was to gather data on the diurnal salivary cortisol secretion cycles of people likely to face socio-economic adversity (by virtue of both their individual and neighbourhood characteristics), and to determine if variation in this cycle, and in overall cortisol levels, exhibited independent association with the level of green space, as objectively measured in their neighbourhoods of residence.

2.2. Choice of sample

In order to maximise exposure to the residential environment (the literature suggests that those at home are more susceptible to green space effects (de Vries et al., 2003)), and to target people likely to face socio-economic adversity, we recruited participants not in work for any reason (unemployed, on invalidity benefit, carers, etc.). Since cortisol secretion is sensitive to age variations, our target sample was men and women aged 35–55 years.

2.3. Method of recruitment

People not in work were recruited via centres in Dundee offering training opportunities for unemployed people, as well as via local community centres. This recruitment process was carried out citywide over a period of 4 weeks in January 2010. In addition to the age criteria stated above, the following inclusion/exclusion criteria were applied.

a. People on particular medications were excluded (e.g. steroids) but more stringent exclusion criteria (e.g. use of anti-depressants, smoking), although recorded, were waived owing to the high likelihood of finding such behaviour patterns in the target sample group.
b. People who had lived for less than 12 months in their neighbourhood of residence were excluded.

At the time of recruitment, participants were asked to complete a short paper-based questionnaire (details below) and were briefed on the protocol for taking cortisol samples. In particular, great care was taken to explain to the participants the necessity to collect the samples at the requested time post awakening, and to inform the research team if they were unable to comply with the instructions.

3. Outcome measures

3.1. Stress measures

Our primary outcome measures related to salivary cortisol. Saliva sampling was chosen over other body fluids (e.g. blood and urine) as it has been shown to accurately represent the biologically active component of circulating cortisol in the blood, allows for repeated measurement, is non-invasive, can be self-administered within the domestic setting and presents the participant no harm (Kirschbaum & Hellhammer, 2000). Outcome measures were average daily levels and the diurnal decline, or slope, of cortisol secretion (nmol/l) derived from multiple saliva sampling across two consecutive days. The purpose of gathering samples over 2 days was to test participant adherence to the protocol (i.e. there should be no significant differences between Day 1 and Day 2 measurements) and enable derivation of a more acute measure of cortisol secretion and diurnal decline (slope) by using the average of 2 days' data. This follows standard good practice for measuring circadian rhythms in salivary cortisol (Edwards et al., 2001).

Our key secondary measure was a self-reported indicator of stress, the Perceived Stress Scale (Cohen, Kamarck, & Mermelstein, 1983), comprising 10 items (e.g. feeling nervous and stressed; feeling on top of things; being angered because of things outside your control) measured on a 5-item response from 'never' to 'very often'. The final score assesses perceived stress over the preceding month and can range from 0 (minimum level of stress) to 40 (maximum level of stress).

3.2. Other individual measures

Mental wellbeing and physical activity were measured as potential explanatory variables. Self-report mental wellbeing was measured using a shortened version of the Warwick and Edinburgh Mental Wellbeing Scale (SWEMWBS, Stewart-Brown et al., 2009). SWEMWBS asks participants how they had felt over the last 4 weeks in relation to 7 items measuring aspects of mental wellbeing (e.g. feeling relaxed, feeling useful, etc.), with responses rated on a 5-item scale from 'none of the time' to 'all of the time'. Final scores can range from 7 (low wellbeing) to 35 (high wellbeing). Physical activity was measured using one item asking for the number of days

on which physical activity (of sufficient exertion to raise breathing rate) reached or exceeded 30 min, recalled over the past 4 weeks, based on 2008 recommendations from the British Heart Foundation National Centre (described and tested for reliability and validity in Milton, Bull, & Bauman, 2011).

As an individual measure of deprivation (based on one used in the annual Scottish Social Attitudes Survey), participants were asked for self-reported perceptions of coping on current income on a scale of 1 (living comfortably on current income) to 4 (finding it very difficult to live on current income). Participants' age and sex were also recorded.

3.3. Area-based measures

Socio-economic deprivation based on the Carstairs Index from the most recent census data available (2001) (Carstairs & Morris, 1991) were obtained via each participant's postcode. This is a widely used and well-validated indicator of area-level socio-economic deprivation based on prevalence of household overcrowding, unemployment among men, low social class, and not having a car. The mean Carstairs score for Dundee is 3.93.

The percentage of a participant's residential environment that was green space was measured objectively using data available at the Centre for Research on Environment Society and Health (Mitchell, Astell-Burt, & Richardson, 2011; Richardson & Mitchell, 2010), again based on each participant's postcode. These data are freely available at the CRESH website (www.cresh.org.uk). The data capture parks, woodlands, scrub and other natural environments, but do not include private gardens. Residential environment was defined by CAS Ward, a geographical unit used in the administration of the UK's decennial census. Dundee contains 31 CAS Wards, with a mean population of 4942 at the 2001 census, and a mean green space value of 33.89%. Previous epidemiological research has identified associations between the amount of green space in a ward of residence, and the health of the residents (Richardson & Mitchell, 2010).

4. Data collection and profile of participants

4.1. Ethics

This study was carried out in accordance with the British Psychological Society 'Ethical Principles for Conducting the Research with Human Participation' and with the full ethical approval granted by the lead researchers' institutional ethics board.

4.2. Cortisol sampling

Average daily levels and the diurnal decline, or slope, of cortisol secretion were derived from multiple saliva sampling across two consecutive days. Data were gathered over the 4-week recruitment period, with participants using Salivette saliva sampling devices (Starstedt, Leicester, UK) on two consecutive weekdays. Participants were instructed to take 4 samples of saliva per day at a time synchronised to their wake up time: 3, 6, 9 and 12 h after awakening. They were instructed not to smoke, eat or drink anything but water 30 min before taking each sample and to keep a log of sample times. Wake up time was defined as the moment a participant was first conscious of being awake. To maximise adherence, participants were sent individualised text prompts, based upon predicted awakening times, 4 times on each day to remind them to take their samples. At the end of the day, participants were asked to freeze their samples (or place in a fridge) in a sealed bag provided. They were then collected and shipped to the laboratory for assay analysis within 5 days of collection.
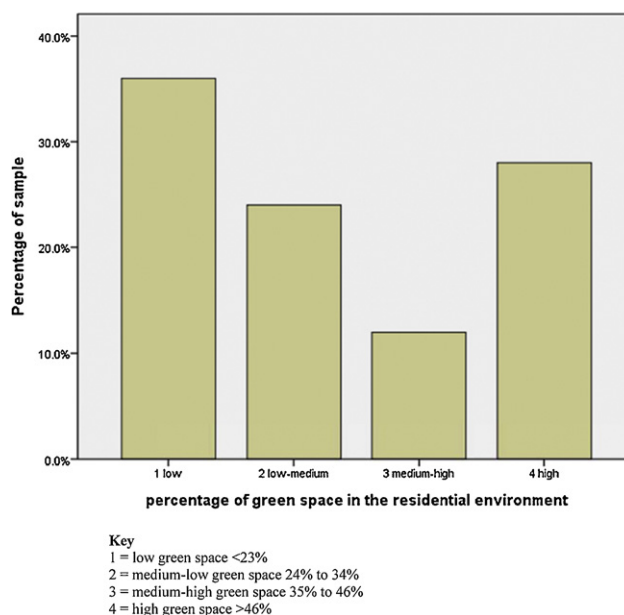

Fig. 1. Distribution of the sample by percentage green space.

4.3. Profile of participants

The number who agreed to participate ($n = 25$) was 33% of those approached for recruitment across a 4-week period, 12 males and 13 females. The mean age of the sample was 43.4 years (SD = 8.2) within an age range of 33–57 years. 72% of the sample was unemployed, with the remainder either in education or looking after family; only 2 participants reported sickness or disability affecting their ability to work. 61% of the sample reported finding it difficult or very difficult to cope on current income levels.

The average Carstairs score for participants' wards of residence was 6.09, indicating high levels of deprivation. The percentage of green space in the residential neighbourhood varied by postcode and ranged from 14% to 74% (median 28.8%); to illustrate the range across the sample, the quartiles by percentage green space are shown in Fig. 1. The figure indicates a greater number of participants living in areas of low and high percentage green space, as compared to medium levels of green space.

The participant numbers for the statistical analyses vary between 20 and 25 owing to occasional missing data due to non-compliance in cortisol protocol (2 participants) or insufficient saliva in some samples (3 participants).

4.4. Stress measures

Cortisol samples were assayed using Enzyme Linked Immuno-Sorbent Assays (Salimetrics, USA). The mean cortisol level was calculated from each of the daily measurement times across days 1 and 2; the slope measurement was the difference in mean measures at 3 h post awakening (sample 1) and 12 h post awakening (sample 4) across Days 1 and 2. The cortisol mean (nmol/l) for the sample ($n = 20$) was 4.58 (SD = 1.67), with the slope measurement mean at 4.64 (SD = 3.64). The self-reported stress (PSS) mean score ($n = 25$) was 19.8 (SD = 6.36).

In order to test adherence to the cortisol sampling protocol over time, we ran a repeated measures ANOVA (analysis of variance) ($n = 20$), factoring day (day 1 and day 2), and sample (i.e. the cortisol mean at 3, 6, 9 and 12 h post-awakening). We found no significant main effect between Day 1 and day 2 for cortisol means. We found a highly significant main effect of time over the day, from

3 to 12 h post-awakening ($F = 8.77$, $df = 3$, $P = 0.001$) indicating, as expected, that cortisol means varied across the day. Both results suggest adherence to the protocol and legitimised our strategy of averaging both cortisol measures (levels and slope) across the 2 sampling days to give the most reliable measures.

4.5. Other health measures

The mean wellbeing (SWEMWBS) score in the sample was 22.72 (SD = 4.83, $n = 25$). Average levels for physical activity ($n = 23$) were below the national recommendations of a minimum of 30 min of moderate to vigorous activity on at least 5 days per week (Scottish Executive, 2003), with the majority of the sample exercising on fewer than 10 days in a 4-week period (mean = 8.65 days, SD = 8.29).

5. Results

5.1. Associations between variables

Relationships between variables were tested using Pearsons bivariate correlations. Associations between cortisol measures, self-reported stress, wellbeing and physical activity measures, and percentage green space in each participant's residential area, are shown in Table 1. Higher mean levels of cortisol were associated with a steeper cortisol slope and with greater wellbeing. Mean cortisol was not statistically associated with physical activity, self-reported stress or percentage of green space in the participant's home environment (although there were trends suggesting a positive association with physical activity and a negative association with self-reported stress).

A steeper cortisol slope (the decline 3–12 h post awakening) was positively associated with wellbeing, physical activity and percentage of green space, and negatively associated with levels of stress.

There was a significant negative correlation between levels of self-reported stress (PSS) and wellbeing and between PSS and the amount of green space in the participant's ward of residence.

5.2. Interpreting patterns of cortisol levels

To interpret the pattern of cortisol levels in the data, it is important to note that a healthy diurnal pattern of cortisol secretion shows a daytime peak shortly after awakening followed by a steep decline as the day progresses (as described earlier).

Within our sample, some participants presented with an average cortisol level and a diurnal slope within the normal range. However, a proportion had lower and flatter cycles than expected from comparable studies of residents in non-deprived neighbourhoods (see Thorn, Evans, Cannon, Hucklebridge, & Clow, 2011 for comparison). To illustrate this, we split the sample on the cortisol slope median (3.92 nmol/l) to give two different groups based on this measure ($n = 20$, 10 men and 10 women) (see Fig. 2). This shows how, in our sample, a higher slope measurement (i.e. a greater change in levels of cortisol between measurements 3 and 12 h post
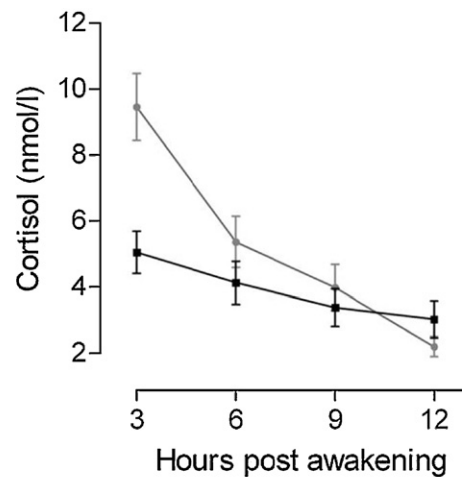
Key: the black line shows the mean pattern of slope for participants with mean slope score ≤ 3.92 (n=10, 4 men, 6 women); the grey shows the mean pattern of slope for participants with mean slope score > 3.92 (n=10, 6 men, 4 women).

Fig. 2. Differences in cortisol slope between sub-groups ($n = 20$).

awakening) was correlated with a higher mean cortisol measurement overall, while the group with a flatter slope ($n = 10$, 4 men, 6 women) had lower mean cortisol levels, marked by lower levels earlier in the diurnal cycle. This latter group's cortisol pattern shows a 'low flat' slope indicative of exhaustion and dysregulation of the cortisol secretion system, as described in Section 1.3 (de Kloet et al., 2007; Giese-Davis et al., 2004; Jerjes et al., 2005; Li et al., 2007; Witteveen et al., 2010). Using a repeated measures ANOVA, the between group difference is significant ($F = 4.993$, $df = 17$, $P = 0.039$). Women had flatter slope profiles than men but the difference was not statistically significant.

5.3. Predicting cortisol slope

To test the association between percentage green space and cortisol slope for potential confounding variables, a linear regression was run to predict cortisol slope, with age, gender, degree of coping on income level, deprivation (Carstairs score), physical activity level and percentage green space in a participant's residential area as the independent variables. The cortisol slope variable met Kolmogorov–Smirnov criteria for normality of distribution. Firstly, the independent variables were entered singly into the model, using the 'enter' method. Of these, only two variables were significant: percentage green space and physical activity. A second regression was then run entering these two variables (again using the 'enter' method). The model showed that both variables are significant predictors of cortisol slope (see Table 2), which equates to better wellbeing. For an increase of one day in physical activity (over 4 weeks) the cortisol slope will increase by 0.2. Green space exposure is also associated with a steeper cortisol slope – for every 1% increase in green space, the slope will increase by

Table 1
Relationships between cortisol patterns, health measures, and green space.

Variable	Cortisol mean	Cortisol slope	Stress	Wellbeing	Physical activity	% Green space
Cortisol mean ($n = 20$)	1					
Cortisol slope ($n = 20$)	0.606[**]	1				
Stress ($n = 25$)	−0.440	−0.561[*]	1			
Wellbeing ($n = 25$)	0.474[*]	0.478[*]	−0.823[**]	1		
Physical activity ($n = 23$)	0.452	0.576[**]	−0.375	0.426[*]	1	
% Green space ($n = 25$)	0.195	0.489[*]	−0.525[**]	0.370	0.186	1

[*] Significant at the $P < 0.05$ level (two-tailed).
[**] Significant at the $P < 0.01$ level (two-tailed).

Table 2
Linear regression model predicting cortisol slope ($n = 20$) over 2 days.

Model	Standardised coefficients	Sig.	95.0% Confidence interval for B	
	Beta		Lower bound	Upper bound
(Constant)		0.930	−2.890	3.142
Physical activity	0.502	0.014	0.050	0.391
% Green space	0.396	0.046	0.001	0.144

Note: the model (SPSS 18 output for coefficients) was significant at $P = 0.005$ with an R^2 value of 0.483.

Table 3
Linear regression model predicting self-reported stress (PSS) ($n = 25$).

Model	Standardised coefficients	Sig.	95.0% Confidence interval for B	
	Beta		Lower bound	Upper bound
(Constant)		0.000	16.544	30.638
% Green space	−0.431	0.051	−0.278	0.001

Note: the model (SPSS 18 output for coefficients) was significant at $P = 0.022$ with an R^2 value of 0.304.

0.07. The VIF (Variance Inflation Factor) values (at 1.04) indicated multi-collinearity was not a problem.

5.4. Predicting self-reported stress

A second regression was run in the same way, but using self-reported stress (PSS) as the dependent variable. PSS data met Kolmogorov–Smirnov criteria for normality of distribution. The same 5 independent variables were entered singularly into the model using the 'enter' method. Of these, percentage green space and gender (reference category male) were significant. When both variables were entered into the model together, percentage green space reached marginal significance (at $P = 0.051$); gender was no longer significant (see Table 3). Self-reported stress and percentage green space were negatively associated, so for every 1% increase in green space, self-reported stress decreased by 0.14 units.

6. Discussion

The main purpose of this study was to test whether the presence of different amounts of green space in the home environment was associated with stress as measured objectively by levels and/or patterns of cortisol secretion over the day, or subjectively by self-reported measures of stress and general wellbeing. We tested these questions, and the viability of the methods used, in an exploratory study in a city in Scotland experiencing higher than national average levels of deprivation.

Firstly, in relation to percentages of green space in the residential neighbourhood, we found a relationship with objective markers of stress as measured by levels and patterns of cortisol secretion. While the methods used are unable to show a causal relationship, we found a significant positive correlation between the diurnal decline in cortisol across the day and percentage of green space (the greater the slope, the greater the percentage green space), and this relationship held after adjusting for demographic and socio-economic variables in a multivariate regression model. The flat cortisol slope associated with lack of green space in this study is indicative of dysregulation of HPA axis function which has been associated with an array of negative health outcomes (Nader et al., 2010). This is an important finding. It represents the 'missing link' between experimental studies which have demonstrated beneficial effects of contact with natural environments on biomarkers of stress (Hartig et al., 2003; Park et al., 2007, 2010; Ulrich et al., 1991) but which cannot be easily generalised to a population level, and population level studies which have demonstrated associations between green space and health outcomes including cardiovascular mortality rates (Mitchell & Popham, 2008) and psychiatric

morbidity (Maas, Verheij, et al., 2009), but which have lacked information on the mechanisms by which the associations are produced. While further work would be needed to establish the degree to which variation in green space use and the quality of green space influence this relationship, the study provides evidence for a salutogenic environment–body interaction which is difficult to test for at a population level but which may lie behind contact with nature in people's everyday living environments.

Secondly, we asked if green space has a relationship with stress and wellbeing as measured by self-report scales. We found an inverse relationship between percentage of neighbourhood green space and self-reported stress (PSS) (marginally significant at $P = 0.051$), showing that people's perceived stress levels increased as the amount of green space in their local environment decreased, and this relationship again held after adjusting for demographic and socio-economic variables.

Subsidiary research questions related to participants' adherence to the cortisol test protocol and the quality of the cortisol sample data; and, finally, whether physical activity levels influence any relationship between measures of stress and of green space levels. Results indicate that our participants largely adhered to the saliva sampling protocol, with missing data in only a few samples owing to insufficient saliva. Furthermore, the consistency of the cortisol data across the 2 study days indicated good levels of compliance to the strict timing requirements (3-hourly) for saliva collection. This is a promising outcome, suggesting recruitment could be effective in a larger sample of the same target population. Contributory factors to adherence to the protocol, we believe, were regular reminders to participants to take samples via mobile telephone text prompts, and the personal briefing of participants by researchers in relation to the project requirements.

We found mixed results on the relationship between physical activity, cortisol measures and subjective stress levels. Regression analyses showed that level of physical activity was a significant predictor of cortisol slope but not of self-reported stress. Physical activity has been shown to reduce stress (Hamer, Stamatakis, & Steptoe, 2009; Tsatsoulis & Fountoulakis, 2006) but perhaps this indirect mechanism is less sensitive to self-report than to objective measures.

In our study, cortisol slope, as a measure of healthy patterns of daily life, has been shown to be a useful measure in studying the relationship between green space and stress: it is an effective biomarker, sensitive to mental wellbeing and self-reported stress, and showing a positive relationship with levels of green space in participants' residential wards.

Daily mean cortisol secretion was less strongly associated with percentage green space. The strongly positive relationship

between diurnal slope and mean cortisol showed that these relationships were in the opposite direction to that which might have been predicted, i.e. the *lower* the mean cortisol levels, the lower the wellbeing. Low and flat cortisol cycles such as found in this study are associated with chronic conditions such as post traumatic stress disorder (PTSD), long term negative life events, repressive anxiety and chronic fatigue (de Kloet et al., 2007; Giese-Davis et al., 2004; Jerjes et al., 2005; Witteveen et al., 2010). Our participants were middle aged and had been residents in the study areas (urban disadvantaged neighbourhoods) for many years. Although we did not measure fatigue, negative life events and trauma in this study, it is plausible that these participants had been exposed to lifetime social disadvantage and negative life events which have resulted in HPA axis dysregulation and the cortisol profiles presented here. Since our sample were not in work, they might be expected to have had greater sickness levels than the general population of the same age living in these locations. Yet most responses to our general health question showed good levels of health, with only two participants reporting sickness or disability. Most interesting, for the purpose of this study, is that those residing within areas of greater percentage green space appear to have been more resilient to the negative effects of urban deprivation and the stress-related consequences.

With regard to self-reported measures of stress and wellbeing, we found several interesting patterns in the data. Firstly, correlations with percentage green space were stronger for the stress scale (PSS) than for the wellbeing scale (SWEMWBS). Secondly, percentage green space showed no relationships with physical activity levels, despite the fact that physical activity was significantly associated with stress as measured by cortisol slope, but not by the self-reported measure (PSS). This suggests that green space is related to subjective stress through mechanisms other than physical exercise.

7. Limitations

We recognised that January in Scotland was not an ideal time of year to explore the impact of green space on stress, given the cold weather and short day length at this time, but the requirement to undertake and analyse an early survey prior to more extended project work later in 2010 necessitated this. It may be that associations between local green space and wellbeing are stronger in warmer months with longer daylight hours. However, our results cannot be attributed to seasonal factors as all participants were studied within the same 4 weeks, living in the same locality.

There is a limitation in our sample size; it reflects the exploratory nature of the research to establish whether recruitment and adherence to the study protocol was possible in a deprived population and a domestic setting. Nonetheless, there was sufficient power in the sample to demonstrate significant findings in relation to our outcome measures. Our sample was not sufficient to allow separate analysis by gender but the literature suggests such differences may be likely: future studies should allow for examination of gender differences in the outcome measures. Our sample is based on a 33% response rate from those approached for recruitment; we are not able to quantify the impact of selection bias in this sample. The low levels of poor health reported by the sample suggest they might be healthier than the typical 'not working' population, but the low and flat cortisol cycles observed suggest that the sample did include those with significant stress problems. In addition, although we were following recommended practice in cortisol sampling, the 2 days of the sample for each participant may have been atypical of their everyday lives.

Owing to limitations in UK land use classification systems, our objective measure of percentage green space was unable to pick up the finer grain detail of front gardens and street trees. Equally, we have not included measures of green views from participants'

homes, the quality of green space or their levels of use, which might contribute explanatory pathways for the findings. Such details suggest important directions for further research.

Perhaps most importantly, our study was cross-sectional and cannot demonstrate causality. Although it builds on experimental studies which have, under controlled conditions, proved that effects similar to those we observed in this study are produced by contact with green space, residual confounding factors remain a possibility. It might be that there is some other property of the greener neighbourhood, or the lives and lifestyles of their residents, which has produced the impact on cortisol slope although, in this study, the relationship with green space was independent of demographic and other SES factors measured.

8. Conclusion

Our study offers new insights into links between green space and health through an approach that measures the diurnal pattern of salivary cortisol as an objective indicator of stress. This approach allows us to assess the association between stress and exposure to green space in a normal, everyday setting, meaningful in socio-ecological terms, rather than in the artificially controlled and time-limited exposures of an experiment. Consequently, our approach offers perhaps greater external validity than previous laboratory and field experiments. We have also shown that reliable salivary cortisol data can be collected from populations living in deprived neighbourhoods, across the day, unsupervised and within the domestic, rather than laboratory, setting.

Using an objective measure of green space has demonstrated associations with health that are independent of quality of green space or perceptions of such space by participants. Our study supports previous epidemiological research in using quantitative estimates of green space but has added to understanding of the underlying mechanism by also using an objective measure of stress. Our findings illustrate one explanatory mechanism behind positive relationships between living in greener environments and health: the regulation of the HPA axis as indicated by diurnal cortisol patterns, showing that greener environments may offer better opportunities for moderating or coping with stress. This supports previous experimental evidence that natural environments might be associated with stress reduction (Grahn & Stigsdotter, 2003; Hartig et al., 2003; Maas, Verheij, et al., 2009; Ulrich et al., 1991) and that such links are particularly relevant to deprived communities (Faber Taylor et al., 2002; Kuo, 2001; Kuo & Sullivan, 2001a). Our findings also suggest that this association is not the result of physical activity per se and point to the likelihood that regular visits to and/or views of green space lie behind the association.

Barton and Pretty's (2010) study of exposure to green space and mental health showed the strongest positive effects on mood and self-esteem for the shortest duration (5 min) of activity in green space, irrespective of activity intensity. It may be that a greener living environment offers more frequent opportunities to experience such benefits as people go about their everyday lives. Such findings suggest that the association between high green space levels and lower stress found in our study may be the result of many minor but nonetheless significant episodes of contact with the natural environment. The need for adequate levels of nearby green space is an important message for landscape and urban planners when designing new residential development, renovating existing urban infrastructure or consulting on land use priorities.

Environment Science and Analytical Services (RESAS) Division and led by The James Hutton Institute in collaboration with the University of Edinburgh and the University of Glasgow.

References

Barton, J., & Pretty, J. (2010). What is the best dose of nature and green exercise for improving mental health? A multi-study analysis. *Environmental Science and Technology*, 44(10), 3947–3955.

Cacioppo, J. T., Kiecolt-Glaser, J. K., Malarkey, W. B., Laskowski, B. F., Rozlog, L. A., Poehlmann, K. M., et al. (2002). Autonomic and glucocorticoid associations with the steady-state expression of latent Epstein–Barr virus. *Hormones and Behavior*, 42, 32–41.

Carstairs, V., & Morris, R. (1991). *Deprivation and Health in Scotland*. Aberdeen: Aberdeen University Press.

Cohen, S., Kamarck, T., & Mermelstein, R. (1983). A global measure of perceived stress. *Journal of Health and Social Behavior*, 24, 385–396.

Coombes, E., Jones, A. P., & Hillsdon, M. (2010). The relationship of physical activity and overweight to objectively measured green space accessibility and use. *Social Science & Medicine*, 70(6), 816–822.

de Kloet, C. S., Vermettena, E., Heijnen, C. J., Geuze, E., Lentjes, E. G. W. M., & Westenberg, H. G. M. (2007). Enhanced cortisol suppression in response to dexamethasone administration in traumatized veterans with and without post-traumatic stress disorder. *Psychoneuroendocrinology*, 32, 215–226.

Deuschle, M., Gotthardt, U., Schweiger, U., Weber, B., Korner, A., Schmider, J., et al. (1997). With aging in humans the activity of the hypothalamus–pituitary–adrenal system increases and its diurnal amplitude flattens. *Life Sciences*, 61, 2239–2246.

de Vries, S. (2010). Nearby nature and human health: Looking at the mechanisms and their implications. In C. Ward Thompson, P. Aspinall, & S. Bell (Eds.), *Innovative approaches in researching landscape and health, Open space: People space 2* (pp. 77–96). Abingdon, UK: Routledge.

de Vries, S., Verheij, R. A., Groenewegen, P. P., & Spreeuwenberg, P. (2003). Natural environments – healthy environments? An exploratory analysis of the relationship between greenspace and health. *Environment and Planning A*, 35, 1717–1731.

Edwards, S., Clow, A., Evans, P., & Hucklebridge, F. (2001). Exploration of the awakening cortisol response in relation to diurnal cortisol secretory activity. *Life Sciences*, 68, 2093–2103.

Faber Taylor, A., Kuo, F. E., & Sullivan, W. (2002). Views of nature and self discipline: Evidence from inner city children. *Journal of Environmental Psychology*, 22, 49–63.

Giese-Davis, J., Sephton, S. E., Abercrombie, H. C., Duran, R. E. F., & Spiegel, D. (2004). Repression and high anxiety are associated with aberrant diurnal cortisol rhythms in women with metastatic breast cancer. *Health Psychology*, 23(6), 645–650.

Grahn, P., Ivarsson, C. T., Stigsdotter, I. K., & Bengtsson, I. (2010). Using affordances as health promoting tool in a therapeutic gardenin. In C. Ward Thompson, P. Aspinall, & S. Bell (Eds.), *Innovative approaches in researching landscape and health, Open space: People space 2* (pp. 120–159). Abingdon, UK: Routledge.

Grahn, P., & Stigsdotter, U. A. (2003). Landscape planning and stress. *Urban Forestry & Urban Greening*, 2(1), 1–18.

Hamer, M., Stamatakis, E., & Steptoe, A. (2009). Dose–response relationship between physical activity and mental health: The Scottish Health Survey. *British Journal of Sports Medicine*, 43, 1111–1114.

Hartig, T. (2007). Three steps to understanding restorative environments as health resources. In C. Ward Thompson, & P. Travlou (Eds.), *Open space: People space* (pp. 163–179). Abingdon, UK: Taylor and Francis.

Hartig, T. (2008). Green space, psychological restoration, and health inequality. *Lancet*, 372(9650), 1614–1615.

Hartig, T., Evans, G. W., Jamner, L. D., Davies, D. S., & Gärling, T. (2003). Tracking restoration in natural and urban field settings. *Journal of Environmental Psychology*, 23, 109–123.

Hartig, T., Mang, M., & Evans, G. W. (1991). Restorative effects of natural environment experience. *Environment and Behavior*, 23, 3–26.

Heinrichs, M., Baumgartner, T., Kirschbaum, C., & Ehlert, U. (2003). Social support and oxytocin interact to suppress cortisol and subjective responses to psychosocial stress. *Biological Psychiatry*, 54(12), 1389–1398.

Hsiao, F. H., Yang, T. T., Ho, R. T., Jow, G. M., Ng, S. M., Chan, C. L., et al. (2010). The self-perceived symptom distress and health-related conditions associated with morning to evening diurnal cortisol patterns in outpatients with major depressive disorder. *Psychoneuroendocrinology*, 35(4), 503–515.

Humpel, N., Owen, N., & Leslie, E. (2002). Environmental factors associated with adults' participation in physical activity: A review. *American Journal of Preventive Medicine*, 22, 188–199.

Jerjes, W. K., Cleare, A. J., Wessely, S., Wood, P. J., & Taylor, N. F. (2005). Diurnal patterns of salivary cortisol and cortisone output in chronic fatigue syndrome. *Journal of Affective Disorders*, 87, 299–304.

Kaplan, S. (1995). The restorative benefits of nature: Toward an integrative framework. *Journal of Environmental Psychology*, 15, 169–182.

Kaplan, R., & Kaplan, S. (1989). *The experience of nature: A psychological perspective*. New York: Cambridge University Press.

Kim, J., & Kaplan, R. (2004). Physical and psychological factors in sense of community – New urbanist Kentlands and nearby orchard village. *Environment Behavior*, 36, 313–334.

Kirschbaum, C., & Hellhammer, D. K. (2000). Salivary cortisol. In G. Fink (Ed.), *Encyclopaedia of stress* (pp. 379–383). Oxford: Academic Press.

Kuo, F. E. (2001). Coping with poverty: Impacts of environment and attention in the inner city. *Environment and Behavior*, 33(1), 5–34.

Kuo, F. E., & Sullivan, W. C. (2001a). Aggression and violence in the inner city: Effects of environment on mental fatigue. *Environment and Behavior*, 33(4), 543–571.

Kuo, F. E., & Sullivan, W. C. (2001b). Environment and crime in the inner city: Effects of environment via mental fatigue. *Environment and Behavior*, 33(3), 343–367.

Kweon, B. S., Sullivan, W. C., & Wiley, A. (1998). Green common spaces and the social integration of inner-city older adults. *Environment and Behavior*, 30, 832–858.

Kyrou, I., & Tsigos, C. (2009). Stress hormones: Physiological stress and regulation of metabolism. *Current Opinion in Pharmacology*, 9, 787–793.

Lee, J., Park, B.-J., Tsunetsugu, Y., Ohira, T., Kagawa, T., & Miyazaki, Y. (2011). Effect of forest bathing on physiological and psychological responses in young Japanese male subjects. *Public Health*, 125, 93–100.

Li, L., Power, C., Kelly, S., Kirschbaum, C., & Hertzman, C. (2007). Life-time socioeconomic position and cortisol patterns in mid-life. *Psychoneuroendocrinology*, 32, 824–833.

Maas, J., van Dillen, S. M. E., Verheij, R. A., & Groenewegen, P. P. (2009). Social contacts as a possible mechanism behind the relation between green space and health. *Health and Place*, 15(2), 586–595.

Maas, J., Verheij, R. A., de Vries, S., Spreeuwenberg, P., Groenewegen, P. P., & Schellevis, G. S. (2009). Morbidity is related to a green living environment. *Journal of Epidemiology and Community Health*, 63, 967–973.

Maas, J., Verheij, R. A., Groenewegen, P. P., de Vries, S., & Spreeuwenberg, P. (2006). Green space, urbanity and health: How strong is the relation? *Journal of Epidemiology and Community Health*, 60, 587–592.

McEwen, B. S., & Stellar, E. (1993). Stress and the individual: Mechanisms leading to disease. *Archives of Internal Medicine*, 153, 2093–2101.

Meerlo, P., Sgoifo, A., & Turek, F. W. (2002). The effects of social defeat and other stressors on the expression of circadian rhythms. *Stress*, 5(1), 15–22.

Milton, K., Bull, F. C., & Bauman, A. (2011). Reliability and validity testing of a single-item physical activity measure. *British Journal of Sports Medicine*, 45, 203–208.

Mitchell, R., Astell-Burt, T., & Richardson, R. (2011). A comparison of green space indicators for epidemiological research. *Journal of Epidemiology and Community Health*, doi:10.1136/jech.2010.119172

Mitchell, R., & Popham, F. (2007). Greenspace, urbanity and health: Relationships in England. *Journal of Epidemiology and Community Health*, 61, 681–683.

Mitchell, R., & Popham, F. (2008). Effect of exposure to natural environment on health inequalities: An observational population study. *The Lancet*, 372(9650), 1655–1660.

Nader, N., Chrousos, G. P., & Kino, T. (2010). Interactions of the circadian CLOCK system and the HPA axis. *Trends in Endocrinology and Metabolism*, 21, 277–286.

Ottosson, J., & Grahn, P. (2005). A comparison of leisure time spent in a garden with leisure time spent indoors: On measures of restoration in residents in geriatric care. *Landscape Research*, 30(1), 23–55.

Park, B. J., Tsunetsugu, Y., Kasetani, T., Hirano, H., Kagawa, T., Sato, M., et al. (2007). Physiological effects of Shinrin-yoku (taking in the atmosphere of the forest) – Using salivary cortisol and cerebral activity as indicators. *Journal of Physiological Anthropology*, 26(2), 123–128.

Park, B. J., Tsunetsugu, Y., Kasetani, T., Kagawa, T., & Miyazaki, Y. (2010). The physiological effects of Shinrin-yoku (taking in the forest atmosphere or forest bathing): Evidence from field experiments in 24 forests across Japan. *Environmental Health and Preventive Medicine*, 15, 18–26.

Penedo, F. J., & Dahn, J. R. (2005). Exercise and well-being: A review of mental and physical health benefits associated with physical activity. *Current Opinion in Psychiatry*, 18(2), 189–193.

Richardson, E. A., & Mitchell, R. (2010). Gender differences in relationships between urban green space and health in the United Kingdom. *Social Science and Medicine*, 71(3), 568–575.

Roe, J., & Aspinall, P. (2011). The restorative benefits of walking in urban and rural settings in adults with good and poor mental health. *Health & Place*, 17, 103–113.

Scottish Executive. (2003). *Let's make Scotland more active: A strategy for physical activity*. Edinburgh: Physical Activity Task Force.

Sephton, S. E., Sapolsky, R. M., Kraemer, H. C., & Spiegel, D. (2000). Diurnal cortisol rhythm as a predictor of breast cancer survival. *Journal of National Cancer Institute*, 92, 994–1000.

Sherwood Brown, E., Varghese, F. P., & McEwen, B. S. (2004). Association of depression with medical illness: Does cortisol play a role? *Biological Psychiatry*, 55, 1–9.

Stewart-Brown, S., Tennant, A., Tennant, R., Platt, S., Parkinson, J., & Weich, S. (2009). Internal construct validity of the Warwick-Edinburgh Mental Well-being Scale (WEMWBS): A Rasch analysis using data from the Scottish Health Education Population Survey. *Health and Quality of Life Outcomes*, 7, 15. doi:10.1186/1477-7525-7-15

Strickland, P., Morriss, R., Wearden, A., & Deakin, B. (1998). A comparison of salivary cortisol in chronic fatigue syndrome, community depression and health controls. *Journal of Affective Disorders*, 47, 191–194.

Sullivan, W. C., Kuo, F. E., & Depooter, S. F. (2004). The fruit of urban nature: Vital neighbourhood spaces. *Environment and Behavior*, 36, 678–700.

Takano, T., Nakamura, K., & Watanabe, M. (2002). Urban residential environments and senior citizens' longevity in megacity areas: The importance of walkable green spaces. *Journal of Epidemiological Community Health*, 56, 913–918.

Thorn, L., Evans, P., Cannon, A., Hucklebridge, F., & Clow, A. (2011). Diurnal cortisol secretion: Seasonal differences in healthy and SAD participants. *Psychoneuroendocrinology, 36*, 816–823.

Tsigos, C., & Chrousos, G. P. (2002). Hypothalamic–pituitary–adrenal axis, neuroendocrine factors and stress. *Journal of Psychosomatic Research, 53*, 865–871.

Tsatsoulis, A., & Fountoulakis, S. (2006). The protective role of exercise on stress system dysregulation and comorbidities. *Stress, Obesity, and Metabolic Syndrome, 1083*, 196–213.

Ulrich, R. S. (1983). Aesthetic and affective responses to natural environment. In I. Altman, & J. F. Wohlwill (Eds.), *Behavior and the natural environment, human behavior and environment, advances in theory and research* (pp. 85–125). New York: Plenum.

Ulrich, R. S., Simons, R. F., Losito, B. D., Fiorito, E., Miles, M. A., & Zelson, M. (1991). Stress recovery during exposure to natural and urban environments. *Journal of Environmental Psychology, 11*, 201–230.

van den Berg, A., & Custers, M. H. G. (2011). Gardening promotes neuroendocrine and affective restoration from stress. *Journal of Health Psychology, 16*(1), 3–11.

van den Berg, A. E., Koole, S. L., & van der Wulp, N. Y. (2003). Environmental preference and restoration: (How) are they related? *Journal of Environmental Psychology, 23*(2), 135–146.

van den Berg, A., Maas, J., Verheij, R. A., & Groenewegen, P. P. (2010). Green space as a buffer between negative life events and health. *Social Science & Medicine, 70*(8), 1203–1210.

Weber, B., Lewicka, S., Deuschle, M., Colla, M., Vecsei, P., & Heuser, I. (2000). Increased diurnal plasma concentrations of cortisone in depressed patients. *Journal of Clinical Endocrinology and Metabolism, 85*, 1133–1136.

Witteveen, A. B., Huizink, A. C., Slottje, P., Bramsen, I., Smid, T., & van der Ploeg, H. M. (2010). Associations of cortisol with posttraumatic stress symptoms and negative life events: A study of police officers and firefighters. *Psychoneuroendocrinology, 35*, 1113–1118.

Wulff, K., Gatti, S., Wettstein, J. G., & Foster, R. G. (2010). Sleep and circadian rhythm disruption in psychiatric and neurodegenerative disease. *Nature Reviews Neuroscience, 11*, 589–599.