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ORIGINAL ARTICLE

The effects of views of nature on autonomic control

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Abstract Previously studies have shown that nature improves mood and self-esteem and reduces blood pressure. Walking within a natural environment has been suggested to alter autonomic nervous system control, but the mechanisms are not fully understood. Heart rate variability (HRV) is a non-invasive method of assessing autonomic control and can give an insight into vagal modulation. Our hypothesis was that viewing nature alone within a controlled laboratory environment would induce higher levels of HRV as compared to built scenes. Heart rate (HR) and blood pressure (BP) were measured during viewing different scenes in a controlled environment. HRV was used to investigate alterations in autonomic activity, specifically parasympathetic activity. Each participant lay in the semi-supine position in a laboratory while we recorded 5 min ($n = 29$) of ECG, BP and respiration as they viewed two collections of slides (one containing nature views and the other built scenes). During viewing of nature, markers of parasympathetic activity were increased in both studies. Root mean squared of successive differences increased 4.2 ± 7.7 ms ($t = 2.9$, $p = 0.008$) and natural logarithm of high frequency increased $0.19 \pm 0.36\ \mathrm{ms^2\ Hz^{-1}}$ ($t = 2.9$, $p = 0.007$) as compared to built scenes. Mean HR and BP were not significantly altered. This study provides evidence that autonomic control of the heart is altered by the simple act of just viewing natural scenes with an increase in vagal activity.

Keywords Environment · Nature · Cardiovascular · Autonomic control · Vagal activity

Introduction

Nature has wide ranging positive effects, but the mechanisms of these effects are not understood, particularly at a physiological level. Cohort study data show that viewing natural landscapes has positive benefits including: improved general health perception (Moore 1982); reduced need for pain relief (Ulrich 1984; Diette et al. 2003; Lechtzin et al. 2010); improved concentration and attention (Berto 2005); improved cognition (Berman et al. 2008); and improved self-esteem and mood (Pretty et al. 2007; Barton et al. 2009).

Meta-analyses (Barton and Pretty 2010) and systematic reviews (Bowler et al. 2010; Thompson Coon et al. 2011) demonstrate the efficacy of exposure to nature in improving psychological well-being, but there is a paucity of studies examining physiological effects (Bowler et al. 2010), possibly due to the difficulties of recording high-quality physiological data outdoors. In addition, to date laboratory studies of viewing natural scenes prove inconsistent (Bowler et al. 2010). When participants viewed slides of rural or built scenes there were no significant differences in heart rate (HR) responses (Ulrich 1981). When exposed to a stressor (elevating HR and blood pressure (BP)) prior to viewing videos of different environments, natural views were deemed more 'restorative' because they elicited more rapid

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returns to baseline HR (Ulrich et al. 1991; Laumann et al. 2003) and BP (Chang et al. 2008). When treadmill exercise was incorporated while viewing slides, BP was lower after a 5-min recovery period after viewing slides depicting natural scenes when compared with slides depicting built environments (Pretty et al. 2005).

To try and understand the physiological effects of nature, one area of interest is the control of the autonomic nervous system (ANS). The ANS is important in the maintenance of homeostasis and also in normal and stress–responsive physiology. One way of investigating ANS control is studying heart rate variability (HRV). HRV is a well-established non-invasive tool which gives an indication of the changes in vagal and sympathetic control of the heart.

Walking or sitting in a natural (forest) environment has previously been shown to lower HR and BP when compared with a built environment control (Park et al. 2010). Park and colleagues suggest that an increase in vagally mediated HRV with simultaneous decreases in sympathetic components is responsible for the observed reductions in HR and BP. Another study with similar engagement with natural environments showed that BP was reduced with a trend to reduced urinary noradrenaline inferring that this was driven by a decrease in sympathetic stimulation (Li et al. 2011).

However, in the outdoor environment, it is difficult to control external factors including the weather. In addition, other elements, including smells and sounds may have positive or negative influences on the ANS. To date, there are only a handful of studies that have explored ANS (Park et al. 2010; Li et al. 2011) and these have not been able to elucidate whether the act of just viewing nature can alter ANS function. Furthermore, these previous studies have also included exercise which is likely to alter the physiological responses.

This is the first study to explore the underlying physiological mechanisms of nature by isolating viewing nature in a controlled environment and comparing the ANS responses to viewing built environments. The use of a controlled environment also allowed the recording of finger BP continually, as well as respiration, both of which can influence HRV measures.

Our hypothesis was that the simple act of viewing nature would alter ANS control with vagal measures of HRV enhanced during viewing nature compared with built views.

Methods

Following ethical approval from the University Ethics Committee, 35 (22 females) volunteers (comprising staff and students from the University (mean (SD): age 39.7 (12.1) years) were recruited following an electronic advertisement. Six individuals were excluded due to taking medication which interfered with HR ($n = 1$), irregular heart rhythms ($n = 4$) or severe obesity prohibiting valid readings ($n = 1$). All remaining participants ($n = 29$) were free from known disease. Participants attended the University laboratory on one occasion.

All participants provided informed consent and completed a health questionnaire (PAR-Q). All testing procedures were carried out between 09:00 h and 14:00 h in a quiet room with a constant temperature of 22–23°C to standardise for potential effects of time of day and temperature, as recommended when conducting autonomic experiments (Tukek et al. 2003). Participants were asked to abstain from food for 2 h and caffeine for 12 h prior to the start of their tests and not to undertake strenuous physical activity in the previous 24 h, as such activities may influence autonomic regulation (Sidery and Macdonald 1994; Stubbs and Macdonald 1995). A diary was kept to ensure compliance.

ECG (modified Lead II configuration) and continuous BP (Portapres, FMS, Finapres Medical Systems BV, The Netherlands) were measured. In addition, respiratory rate and depth were recorded using a respiratory belt transducer placed around the lower part of the chest. This strap contains a piezo-electric device that responds linearly to changes in length induced by chest movement due to breathing. Breathing rate and depth over each 5-min segment were analysed to ensure that there were no significant alterations in these parameters.

Participants rested in the semi-supine position to allow their HR and BP to stabilise and remained in this position for the rest of the experiment. All data were sampled at 1,000 Hz and collected by a Powerlab 8SP (Model ML785, ADInstruments, UK), using Chart 4 software (ADInstruments, UK).

Testing commenced after 15 min of rest to ensure stabilisation of HR. Participants were shown two collections of slides during the same session. One slideshow contained natural scenes and the second set incorporated built or urban scenes lacking greenery (Fig. 1). Participants were asked to imagine they were in the environment. Slides were projected on to a screen (1.8 m × 1.8 m) situated in front of the participant.

Half of the participants viewed the natural environment set of slides first followed by the built environment slides in a randomised crossover design. The other participants viewed the built slides first. Ten minutes between the two sets was allowed, with participants remaining quiet and still in a semi-supine position whilst looking at a blank screen. Each slideshow (18 slides) lasted for 5 min with each slide shown for 17 s. Slides within a slideshow were always shown in the same order. HR, BP and respiration measurements were recorded for the whole of the 5 min whilst viewing the slideshow.

Fig. 1 An example of the slides taken for the built slideshow (**a**, **b**) and from the natural slideshow (**c**, **d**). There were 18 slides in each slide show with each slide shown for 17 s

Data analysis: heart rate variability

ECG data were analysed using Kubios HRV software (Niskanen et al. 2004) (http://www.kubios.uku.fi). Data for each set of slides were analysed and averaged over the 5 min periods of viewing slides of either natural or built environments. No aberrant or ectopic beats were identified. RR intervals were then extracted from the ECG signal and re-sampled at 4 Hz using cubic spline interpolation to provide equidistant time points. In the time domain, the mean R–R interval and HR, standard deviation of RR intervals (SDRR) and root mean square of successive differences (rMSSD) were calculated as recommended (Task Force 1996). Data then underwent Fast Fourier transformation (non-parametric) using Welch's periodogram method. Data were split into windows of a width of 256 s with an overlap of 50%. The power spectrum was obtained by averaging the spectra within these windows. Two spectral components of the recording were analysed: low frequency (LF, 0.04–0.15 Hz) and high frequency (HF 0.15–0.40 Hz) spectral power, in accordance with international guidelines (Task Force 1996). HF provides an indication of parasympathetic activity, whereas LF oscillations result from the combined activity of both autonomic nervous system branches (Task Force 1996).

Non-linear analysis was performed using Poincaré plot analysis, a graphical representation of the correlation between successive RR intervals with SD1 indicating short-term variability (analogous to rMSSD and HF) and SD2 indicating overall variability (analogous to SDRR) (Brennan et al. 2001).

Data analysis: blood pressure and baroreceptor sensitivity

Combined measurements of HRV and BP variability give information on both parasympathetic and sympathetic nervous system activity. Systolic, diastolic and mean BP values were detected from the measured BP signal for each heart beat. Systolic BP (SBP) and RR time series were used in baroreceptor sensitivity (BRS) estimation (the BP value was as compared to the following RR interval). Both were first interpolated at 4 Hz and de-trended with smoothing prior method. BRS values were estimated using two methods: multivariate autoregressive (AR) spectral estimation method and sequence analysis. Power spectra were first calculated by fitting a multivariate AR model of order 22 to RR and SBP time series. AR coefficients were then used to calculate power, coherence and phase spectra (Di Rienzo et al. 2001). BRS estimates were calculated from the spectra using the frequency–domain alpha technique. Values were calculated for LF (0.04–0.15) Hz and HF (0.15–0.4 Hz). Spectrum values were calculated in 301 points between 0 and 2 Hz and only where coherence was higher than 0.5 and phase was below 0 were accepted to the sum of spectrum power.

The sequence method was also used to estimate BRS values. Sequences were detected from the original signals where RR interval and SBP value both ascended or when both descended at the same time for at least three consecutive intervals. Minimum change that was accepted was 5 ms for RR and 1 mmHg for SBP. A regression line (RR as a function of SBP) was fitted to the detected sequences, and then correlations between these variables were calculated (Pearson's correlation coefficient), and those with $r > 0.85$ were accepted. The BRS value was then obtained as the mean slope of the regression lines fitted to all accepted sequence points (Di Rienzo et al. 2001).

Data analysis: respiration

The respiratory trace was analysed offline in Chart by looking at cyclic variables and obtaining average cycle length, and average of maximum peak height and average of peak minimum height and average cycle height were calculated (Table 2).

Statistical analysis

Paired *t* tests were used to statistically analyse the data for the effect of the two types of view (natural versus built) with significance set at $p \leq 0.05$. Paired *t* tests were also used to statistically analyse the data for the effect of slide show one compared with slide show two (irrespective of type of view) with significance set at $p \leq 0.05$. All the data given are normally distributed except for absolute values for HF and LF (as assessed by Kolomogorov–Smirnov test for normality). The effect size was calculated using Cohen's *d* for all physiological variables.

Results

Twenty-nine participants were included in the analysis. Mean HR, systolic BP (SBP) and diastolic BP (DBP) were similar while viewing natural or built environment images (Table 1). The effect sizes for all these were very small (*d* range 0.04–0.19) (Table 1).

Table 1 Cardiovascular variables during the two different slide viewings: nature and built

	Nature	Built	Significance	Effect size
HR (bpm)	62.6 (9.2)	62.6 (9.3)	0.9	0.04
SBP (mmHg)	116.4 (10.3)	118.4 (11.0)	0.15	0.19
DBP (mmHg)	59.0 (11.0)	59.8 (9.0)	0.25	0.08

Data are shown as mean (SD); $n = 29$. Effect size is also shown (Cohen's *d*)

HR mean heart rate, *SBP* systolic blood pressure, *DBP* diastolic blood pressure

Table 2 Respiratory values during the two different slide viewings: nature and built

	Nature	Built	Significance
Duration of 1 breathing cycle (s)	4.4 (0.8)	4.2 (0.8)	0.12
Average minimum peak height	−1.1 (2.1)	−1.3 (1.6)	0.27
Average maximum peak height	3.3 (2.9)	3.1 (2.5)	0.23
Average cycle height	4.4 (3.0)	4.4 (3.1)	0.89

Data are shown as mean (SD), $n = 29$

There were no significant differences in breathing depth or cycle duration between the different views (Table 2).

Time domain (SDRR, rMSSD), and non-linear (SD1) indices of vagal outflow were all significantly higher when viewing natural versus built environments (Fig. 2; Table 2). 23/29 participants increased rMSSD whilst viewing nature as compared to built views (Fig. 2). Following natural log transformation of HF (lnHF), there was also a significant difference in lnHF between natural and built environment views with 21/29 participants with increased lnHF whilst viewing nature as compared to built views (Fig. 2). Effect sizes for vagal indices were moderate (Table 3).

BRS values using AR analysis in the HF domain (BRS-HF) were significantly greater during viewing natural scenes compared to built scenes (Table 4). BRS values obtained using sequence analysis (BRS-UP) were significantly higher while viewing natural environments, whilst BRS-combined was also close to statistical significance ($p = 0.06$) (Table 4). Effect sizes for BRS variables are classed as small to moderate (Table 4).

An analysis of order effect was undertaken to ensure responses were due to the images on the slides and not which set of slides was presented first. No significant differences were found for any parameters.

Discussion

Previous experimental work suggests exercising in nature improves mental health, in particular mood and self-esteem (Pretty et al. 2005, 2007; Barton et al. 2009; Barton and Pretty 2010; Bowler et al. 2010; Thompson Coon et al.

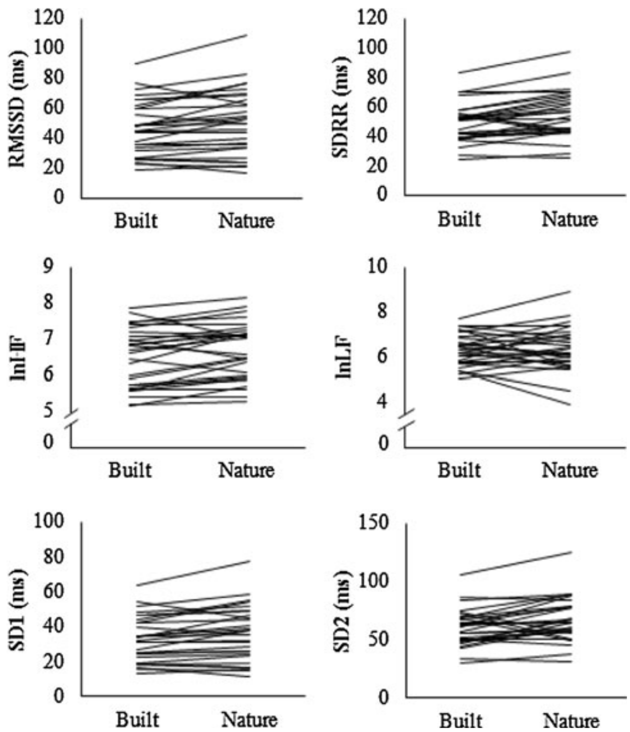

Fig. 2 Individual comparisons of responses to built and nature views for **a** rMSSD, **b** SDRR, **c** lnHF, **d** lnLF, **e** SD1, **f** SD2 (see text for explanation of abbreviations). Built is shown on the *left* of each *graph* with nature on the *right*

Table 3 Measures of HRV during the two different slide viewings: nature and built

	Nature	Built	Significance	Effect size
Overall variability				
SDRR (ms)	54.2 (16.0)	49.0 (13.2)	0.001	0.35
lnLF	6.36 (1.0)	6.32 (0.7)	0.8	0.04
SD2	67.0 (19.1)	60.3 (16.1)	0.008	0.38
Vagal mediated				
rMSSD (ms)	50.6 (22.1)	46.4 (18.6)	0.008	0.32
lnHF	6.65 (0.8)	6.45 (0.8)	0.007	0.23
SD1	35.8 (15.6)	32.8 (13.1)	0.008	0.21

Data are shown as mean (SD), $n = 29$. The absolute values for HF are 1,039.7 (with range 193.8–3,516.8) $ms^2 Hz^{-1}$ and 868.1 (range 172.9–2,629.7) $ms^2 Hz^{-1}$ collected during viewing natural and built scenes, respectively. The absolute values for LF are 709.2 (with range 158.1–2,268.9) $ms^2 Hz^{-1}$ and 970.0 (range 51.4–7,443.8) $ms^2 Hz^{-1}$ collected during viewing natural and built scenes, respectively. All the data shown are normally distributed except for absolute values for HF and LF (as tested by Kolomogorov–Smirnov test for normality). Effect size is also shown (Cohen's *d*)

SDRR standard deviation of RR interval, *lnLF* natural log of low frequency spectral power (0.04–0.15 Hz), *SD2* long-term variability Poincare plot, *rMSSD* root mean squared of successive differences, *lnHF* natural log of high frequency spectral power (0.15–0.4 Hz), *SD1* short-term variability Poincare plot

Table 4 Measures of BRS during the two different slide viewings: nature and built

	Nature	Built	Significance	Effect size
BRS-HF (ms $mmHg^{-1}$)	23.1 (11.9)	20.5 (8.5)	0.008	0.25
BRS-UP (ms $mmHg^{-1}$)	15.9 (9.6)	12.9 (5.1)	0.048	0.39
BRS-combined (ms $mmHg^{-1}$)	14.5 (5.6)	13.7 (5.6)	0.06	0.15

Data are shown as mean (SD), $n = 29$. These measures generally reflect vagally mediated changes. Effect size is also shown (Cohen's *d*)

BRS baroreceptor sensitivity, *BRS-HF* derived from cross-spectral analysis, *BRS-UP* and *BRS-combined* derived from sequence analysis

2011). However, fewer studies report physiological responses (Bowler et al. 2010) and the underlying physiological mechanisms involved in viewing nature alone are unclear. Within a laboratory setting, previous studies have measured HR (Ulrich et al. 1991; Laumann et al. 2003) and blood pressure volume (Chang et al. 2008) after inducing stress first to alter baseline values. The nature views appeared to have a restorative effect with greater decreases towards baseline values after the stressor when viewing nature environments as compared to viewing built environments. In addition, following an outdoor walk in nature, urinary noradrenaline levels were found to be lower versus a built walk (Li et al. 2011). However, all of the previous papers have inferred that changes in physiological measures are likely to be induced by the ANS, but have not measured ANS control using established methods. Only one previous study has explored the role of the ANS using HRV, and this was conducted whilst the participants were exposed to real environments (Park et al. 2010). Although real environments allow investigations to be ecologically valid, it makes it more difficult to undertake a well-controlled study to investigate ANS mechanisms. Our study is the first to explore ANS control in a controlled environment, also enabling BP and respiration to be measured simultaneously.

In the current study, alterations in cardiovascular autonomic control (in particular vagal activity) were measured by the use of well-established non-invasive measures of HRV and BRS. HRV and BRS-HF increased significantly during the viewing of nature compared with built environment scenes, suggesting increases in vagal activity. This suggests that the simple act of viewing nature may induce changes in autonomic control, in particular vagal activity. In the current study, the increases in vagal activity are present without prior exercise or stress inducing components, or the additional factors that are present in a real environment. The real environment and prior exercise may act synergistically with the nature views to produce greater physiological effects. However, in this study, we wished to explore, in a controlled environment, the underlying physiological mechanisms of the effects of nature views without the effect of prior exercise or stress.

It is likely that the views of nature induced relaxation and indeed Park et al. (2010) suggest the augmented vagal activity they observed while participants were engaged with nature was due to relaxation. Relaxation is also proposed to occur via stress reduction (Ulrich 1981; Ulrich et al. 1991) or alterations in attentional capacity (Kaplan and Kaplan 1989). In earlier studies, EEG has shown an increase in alpha waves (suggesting relaxation) when viewing nature, but they did not define particular areas of the brain (Ulrich 1981). Anecdotally, our participants reported a preference for viewing the natural scenes and feeling more relaxed. Relaxation can cause changes in breathing rate and depth and these in turn can affect HRV. In the current study, due to the controlled environment, breathing rate and depth were able to be measured and were not significantly different between the views with a breathing frequency at 0.24 Hz. We did not control breathing frequency as previous papers show that HRV measures are not significantly affected by controlled or free breathing if HR is within normal ranges (Patwardhan et al. 1995; Bloomfield et al. 2001). We do understand the need for breathing rate not to be significantly different for a participant in the two conditions. In practical terms, we believe that in this study asking participants to breathe to a metronome may have caused a distraction from viewing the scenes and thus altered the physiological effects of viewing.

The rigorous application of established autonomic measures in a controlled environment advances existing physiological research in this area. The controlled environment allowed the act of viewing natural environments to be isolated and eliminated other factors that may alter physiology when humans are exposed to built or natural environments. These include potentially negative factors, such as noise, air pollution or potentially positive factors, such as natural sounds and phytoncides (Li et al. 2011). The authors of previous studies suggest that the effects in cardiovascular markers are caused by walking or being surrounded by the relaxing forest environments (Park et al. 2010) with the natural fragrance of trees (phytoncides) contributing to the reduction in BP and attenuation of biomarkers in the blood and urine, including noradrenaline (Li et al. 2011). They suggest BP reductions may be due to a decrease in sympathetic activity and an increase in parasympathetic activity. The exercise component itself could contribute to some of the reduction in sympathetic activity and increase in parasympathetic activity, although the BP reductions were greater following nature walks, suggesting an additional effect of nature.

Previous experiments that have used the controlled environment of a laboratory have generally used prior exposure to a stressor to increase participants' HR and BP before examining recovery and have not measured ANS activity. Improved recovery of HR (Ulrich et al. 1991; Laumann et al. 2003) and BP (Chang et al. 2008) while viewing natural scenes after exposure to a stressor has led to nature being regarded as 'restorative'. In contrast to the previous experiments, we were interested in exploring the direct effects of viewing nature on HRV and BRS at rest without the addition of exercise or a stressor to establish the physiological mechanisms of viewing nature alone. Unfortunately, the physiological changes are less dramatic when changes are investigated from baseline values, especially in a well-controlled experiment, where the participant should be relaxed prior to taking part in the experimental conditions. At rest, the body aims to maintain homeostasis, and large decreases were not expected in the already low, resting values in our study for HR (62 beats per minute) or BP (117/59 mmHg) on exposure to nature. It would be highly unlikely and unusual for an individual's HR to drop by 5 beats per minute from this level, which would be needed to show a significant difference. However, it may be expected that HR would decrease, in conjunction with the increase in HRV, but this was not the case. This is unsurprising since mean HR cannot reflect the oscillating influences on cardiac vagal neurones (Gilbey et al. 1984). In a previous study involving respiratory training, HRV was measured alongside other markers of vagal activity (including measures of HR recovery following exercise), and all markers indicated that vagal activity increased despite no significant change in HR (Hepburn et al. 2005). However, HRV is a sensitive indicator of ANS function and in particular vagal activity and the utilisation of such measures adds to existing laboratory data (Ulrich 1981; Ulrich et al. 1991; Laumann et al. 2003; Berto 2005; Pretty et al. 2005; Berman et al. 2008; Chang et al. 2008) as it provides, for the first time, information on how viewing nature affects the ANS and the interaction of HR and BP in terms of baroreceptor activity. However, for comparisons to be made within participants, respiratory frequency and depth should not be significantly altered, as was the case in our study.

Increases in HRV measures may have an important physiological relevance, despite the lack of significant changes in HR and BP. The alterations that are seen in lnHF, rMSSD and SD1 give an indication of the degree of influence on cardiac vagal neurones at respiratory frequencies (Task Force 1996), i.e., it does not necessarily imply that there is an increase in overall vagal tone, but suggests increased vagal phasic activity. Afferent input from higher centres and/or from feedback mechanisms (e.g. baroreceptors and chemoreceptors) induce changes in vagal neurone outflow from the nucleus tractus solitarii (NTS). Increases in vagal neurone outflow can be caused by an increase in synaptic excitatory input to cardiac vagal neurones; or a decrease in inhibition elicited by inspiratory drive; or both. At rest, during normal breathing (as was the case in our study), if there is an increase in vagal neurone excitability (maybe via baroreceptor influence), R–R interval will increase. This can be followed by a rebound inhibition of these vagal neurones by inspiratory drive, decreasing R–R interval to a greater extent, giving augmented HRV values, but with an unchanged mean HR. This is likely to be the case in our participants. The baroreceptors may play a role in maintaining homeostasis as BRS is elevated during nature views.

The cause of the increase in vagal excitability is very interesting, and it is likely that the nucleus ambiguus containing the vagal neurones is influenced by other areas of the brain. Some of the images that we used in our current study were examined for how aversive and uncomfortable they were by examining their spatial frequency properties (Fernandez and Wilkins 2008). Our nature images were found to be more pleasant and less aversive. Interestingly, in a recent study which used MRI during natural and urban views different areas of the brain were stimulated depending on which scenes were viewed (Kim et al. 2010). The visual cortex was stimulated more in the urban views than the natural views. These findings may suggest that in part, the increase in vagal activity may be because the nature images have less impact on the visual system, with nature images being able to be processed more efficiently and inducing different changes within the visual cortex than images of built slides. The influence of visual cortex and other areas of the brain (maybe the frontal cortex) are likely to be mediated via the left insular cortex, a region containing neurones that excite cardiac vagal neurones selectively via the amygdala as increases in amygdala excitation have been associated with inhibition of parasympathetic activity (Thayer and Lane 2009).

Although the results show alterations in HRV measures for both overall variability and what is considered to be vagally mediated variability, there were no significant changes in HR and BP, which may be considered as important functional measures. Without significant alterations in HR and BP, this may limit the conclusions that can be drawn from the present study.

A further limitation of the study is that although there are statistically significant differences between the two views, inter-individual differences exist in responses to the slides. This might be due to a lack of continuous engagement from the participants with the projected scenes throughout the whole slideshow, i.e., the participants' minds wandering. Alternatively, participants may have varying affinities to nature which results in different responses towards the scenes viewed in this study.

Future studies are needed to explore the mechanisms and in particular physiological changes that occur in response to nature, taking into consideration individual differences and affinity to nature. This study provides an important basis to start to derive explanations of changes that are seen in cohort and epidemiological studies.

Conclusion

This study shows for the first time that the simple act of viewing natural scenes, without the additional factors found in a real environment, may induce changes in autonomic control via increases in vagal modulation. The increases in vagal activity are evident without prior exercise or stress inducing components.

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Conflict of interest None.

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