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Color aesthetics: A transatlantic comparison of psychological and physiological impacts of warm and cool colors in garden landscapes

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ABSTRACT

Evidence shows green space exposure has beneficial impacts on psychological and physiological wellbeing. However, aesthetic differences in color use in cultivated garden landscapes on wellbeing remains unexplored. This study investigates how warm and cool colored garden landscapes affect psychological and physiological wellbeing and how responses differ geographically.

Our between subjects design used USA and UK participants exposed to videos of static garden landscapes consisting of (a) warm colors, (b) cool colors and (c) control images. Measures of subjective psychological wellbeing (UWIST Mood Adjective Checklist (MACL)) and biometrics of stress using the Empatica E4 watch (Heart rate; Heart Rate Variability (HRV); Skin Temperature; Galvanic Skin Response (GSR) and Photoplethysmography) were obtained to ascertain if warm and cool colored cultivated garden landscapes affected psychological and physiological responses.

Results showed statistical differences between locations in psychological and physiological wellbeing. USA participants experienced increases in hedonic tone and decreases in perceived stress after viewing warm and cool colored garden landscapes, a result not found in UK participants. Physiological indicators show geographical differences with beneficial effects of warm colors in the USA, shown in HRV and GSR measures relative to control. The UK sample presented mixed evidence regarding positive effects of warm and cool colored garden landscapes on physiological measures.

These findings show stronger psychological and physiological responses to color in the US sample compared to a UK sample, suggesting geographic disparities in these responses to plant color. This should be further explored to understand color choice for landscape design to optimize outdoor settings that maximize wellbeing.

1. Introduction

Viewing static images of green spaces has a beneficial impact on psychological restoration (i.e. the recovery of depleted cognitive resources) through improved attentional capacity (Kaplan and Kaplan, 1989; Staats et al., 2003; van den Berg et al., 2003) and stress reduction (Roe et al., 2013; Ulrich et al., 1991; Ward Thompson et al., 2012; Chalmin-Pui et al., 2021a). Beneficial impacts have been demonstrated through both physical, in-situ exposure to nature and laboratory set- tings by employing image banks showing relatively vast nature images. Recent research suggests that the beneficial effects of nature can be achieved even within dense urban areas (Chalmin-Pui et al., 2021a; Chalmin-Pui et al., 2021b; de Bell et al., 2020). For example, exposure to community and domestic gardens can result in benefits to personal and social health (Howarth et al., 2020; South et al., 2018; Wakefield et al., 2007), while gardens in care facilities can provide mood benefits to clinical populations (White et al., 2018). There is also evidence to suggest that the inclusion of plants in the home and workplace can reduce indoor air pollutants and regulate relative humidity (Gubb et al., 2020), provide psychological benefits (Bringslimark et al., 2007), improve mood (Deng and Deng, 2018), provide physiological benefits (Lee et al., 2015), improve productivity (Larsen et al., 2016), increase positive emotions and reduction in negative emotions (Han and Ruan, 2019) and reduce sick days (Fjeld, 2000).

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While there is a consensus that health benefits can be derived from green space, gardens and plants specifically, there is less evidence on how garden and planting design can maximize wellbeing impacts. In terms of planting aesthetic and style, evidence suggests that natural-looking, informal gardens have an increased benefit over formal gardens (Elsadek et al., 2016; Twedt et al., 2016). People have also been found to prefer plantings with colorful flower cover (Hoyle et al., 2017; Todorova et al., 2004), as well as radially symmetrical flowers (Bertamini et al., 2019; Hůla and Flegr, 2016). Such preferences have been associated with psychological restoration (Kuper, 2020) and raise questions about the effective use of color in cultivated gardens and its impact on eventual wellbeing benefits. Recent studies have evaluated color differences in various landscape settings such as schoolyards using artificially rendered images (Paddle and Gilliland, 2016) or manipulated photographs from real environments (Wang et al., 2016). These studies found that autumn foliage was perceived to be restorative (Paddle and Gilliland, 2016) and that landscapes with a high degree of vegetation generate stronger consensus around visual aesthetic quality (Wang et al., 2016).

There is increasing evidence that plants of different colors can have a differentiated impact on emotional, psychological and physiological wellbeing (Elsadek et al., 2016; Hůla and Flegr, 2016; Kuper, 2020; Jang et al., 2014; Kaufman and Lohr, 2004; Mok et al., 2006). For example, Kuper (2020) demonstrated that flowering plants and autumnal foliage had a higher restorative potential than green foliage. On the other hand, yellow foliage elicits a negative physiological response as, evolutionarily, it may indicate nutrient deficient trees (Kaufman and Lohr, 2004). Similarly, variegated ivy elicited different emotional reactions depending on the color patterns and combinations (Elsadek et al., 2016). Akers et al. (2012) showed that green-filtered nature videos led to less mood disturbance and lower perceived exertion compared to a red filter video that led to higher levels of perceived anger.

These results can be expected as color is widely recognized to have an impact on human emotions (Hogg, 1969; Wright and Rainwater, 1962). According to Berlyne (1971), visible changes in color hues affect arousal level, with warm colors such as red being associ- ated with high arousal, as compared to cool colors such as blue and green (Elliot, 2019). Classic color perception studies have shown in- creased state anxiety (Jacobs and Suess, 1975) and increases in phys- iological arousal, measured by galvanic skin response when viewing warm colors compared to cool color (Jacobs and Hustmyer, 1974). How- ever, reds have also been rated as more pleasant than yellow and green- yellow, and less arousing that blues and greens (Valdez and Mehrabian, 1994).

While it has been argued that there are universal preferences for some colors over others (Eysenck, 1941; Ou et al., 2004a; Ou et al., 2004b; Ou et al., 2004c), cross-cultural investigations of color preference have acknowledged some cultural variation when comparing the color preferences of two or more cultures (Hurlbert and Ling, 2007; Sorokowski et al., 2014). For example, gender differences in color preference are modulated by cultural context, as shown by a comparison of Chinese and UK populations (Hurlbert and Ling, 2007) and of Polish and Papua (Indonesia) populations (Sorokowski et al., 2014). The commercial implications of color preferences have been studied in the cut-flowers and plant retail industry (Behe et al., 1999; Yue and Behe, 2010). However, few studies have looked at the geographical differences of color preference and any associated emotional, psychological or physiological responses to color in a garden landscape setting.

In summary, exposure to green spaces has led to demonstrable improvements in physiological outcomes, including heart rate and blood pressure (Kondo et al., 2018; Twohig-Bennett and Jones, 2018), but, as yet, there is little evidence to isolate the role of color or geograph- ical differences in response to color. This study aimed to understand if psychological and physiological color responses vary between USA and UK participants viewing formal garden landscapes. This is impor- tant as these spaces are designed to benefit users, though little work has attempted to understand the benefit of color plantings in these formal settings. Our research questions are:

Research Question 1: What are the differences in psychological and physiological responses to warm vs. cool color garden landscape images within our sample?

Research Question 2: Are there geographical differences in psychological and physiological responses to warm vs cool color garden images between participant groups in the USA and UK?

2. Materials and methods

2.1. Participants

All participants (n = 84) were adults aged between 18 and 35 years and completed the same research protocol at the two study locations in the USA and UK. Ethical approval for the study was provided by the University of Virginia Institutional Review Board for Social and Behavioral Sciences (IRB-SBS) with informed and signed consent a condition of taking part in the study.

USA: 48 participants (35 female and 13 male) took part in this study in Charlottesville, aged between 18 and 32 years (mean age = 21.4 years). USA participants were recruited through a University of Virginia participant pool database (Behavioral Research at Darden (BRAD) Lab, Darden School of Business) – recruiting staff and students across the University. Testing for this group took place in October 2018.

UK: 36 participants (26 female and 10 male) took part in this study in Sheffield, aged between 19 and 35 years (mean age = 25.1 years). Participants were recruited through the University of Sheffield staff and student volunteer mailing lists. Testing for this group took place in October 2019.

The one year difference between the data collection periods for the two populations was in order to control for seasonal changes in local outdoor environments. Both Charlottesville and Sheffield experience autumnal foliage in October, so both groups of participants would have been recently exposed to seasonal variation in vegetation colors in their everyday lives at the time of the experiment (autumn).

2.2. Stimuli

Three videos were created for this study protocol; each video was a slide show of still images, with a total of nine images, each lasting for 20 s (total duration = 180 s per video). YouTube links to each of the videos can be found in the Supplementary Material. Both the warm and cool color landscape images were images of examples of garden landscapes, as described below. The videos were as follows:

1. Warm color landscape – images of garden landscapes and green space that have a color palette made up of reds, yellows and oranges.
2. Cool color landscape – images of garden landscapes and green space that have a color palette made up of violets, blues and whites.
3. Control - Black and white images of everyday household items that have no visual properties related to either color nor garden landscapes. This controlled for any impact that viewing color and/or garden landscapes may have in isolation of each other.

2.3. Experimental design and procedure

Upon arrival, participants were given time to read the experimental information, ask any questions and sign the consent form. After signing the consent form, the Empatica E4 was placed on their non-dominant wrist and set up to stream and save the real time data. Participants were taken to a single-user testing room where they undertook a color blindness test (https://enchroma.com/pages/test) to ensure that they were able to differentiate between color manipulations. Participants had a five minute resting period where they were asked to sit quietly and still in order for the physiological signals to reach a baseline resting rate.

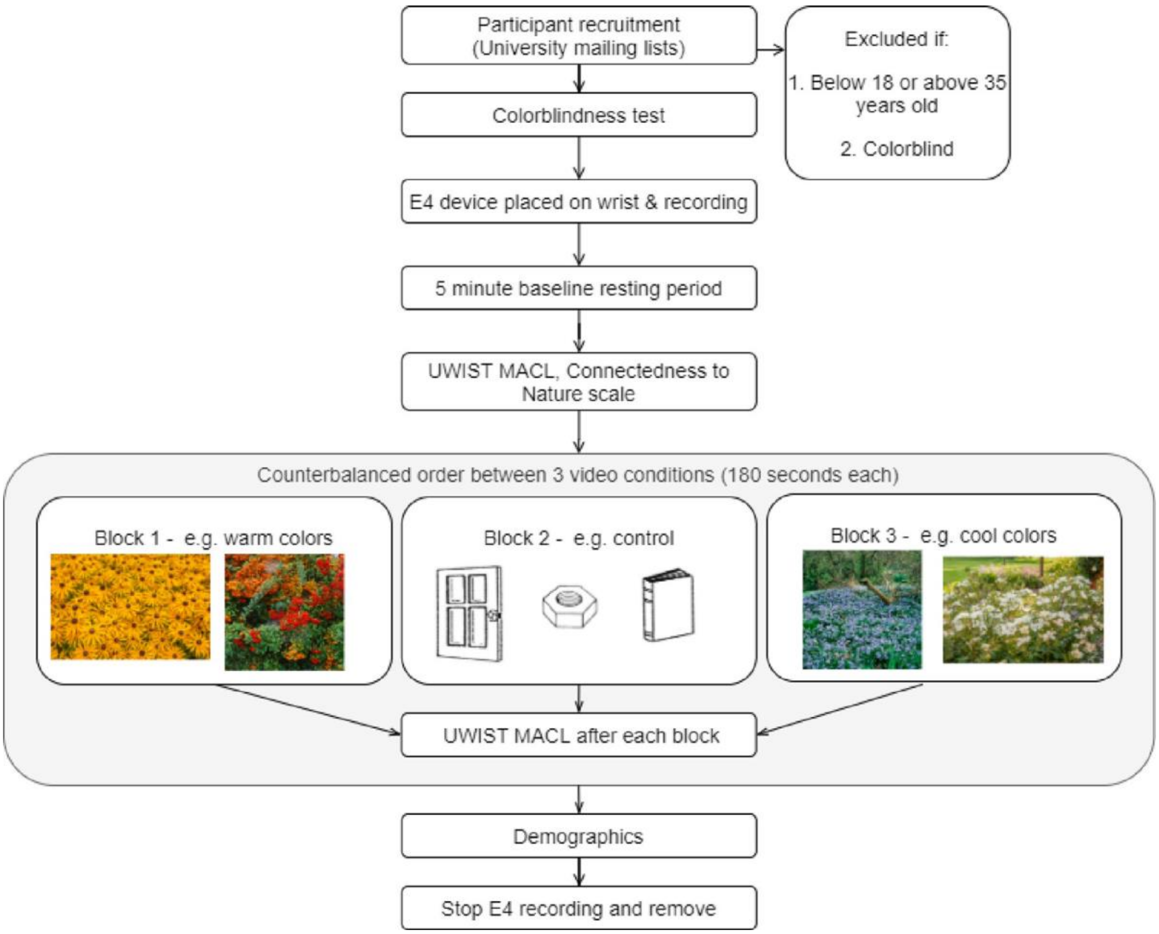

Fig. 1. Experimental procedure including examples of images from each condition.

The Connection to Nature scale (CNS) scale and the first Mood Adjective Checklist (MACL) was completed at the end of this resting baseline period. Following this, participants were shown the video stimuli on a standard desktop computer screen. Participants watched three image block videos (each 180 s) in a random, counterbalanced order, with a short break between each one for participants to complete repeated MACL measures. Once all three videos had been viewed, a demographic questionnaire asked participants for their age and gender. All stimuli and questionnaires were run and hosted on a single Qualtrics survey. The flow of the procedure is displayed in Fig. 1.

2.4. Outcome measures

2.4.1. Psychological measures

The University of Wales Institute of Science and Technology Mood Adjective Checklist (UWIST MACL) was used pre- and post-exposure to video stimuli to determine acute subjective mood changes, giving measures of hedonic tone (pleasantness of mood), stress (subjective tension) and arousal (energy), expressed as three distinct scores (Matthews et al., 1990). They respond to 24-items each on a 4-point scale [definitely, slightly, slightly not, definitely not], with each point scored from 1 to 4. Each subcomponent (hedonic tone, stress and arousal) is measured across eight descriptors and scores for each range from 8 to 32 with higher scores indicating higher hedonic tone (positive valence, stress or arousal).

The Connectedness to Nature scale (CNS) was used to obtain each participant's trait emotional connection with nature (Mayer and Frantz, 2004). Participants respond to 14-items each on a 5-point scale ['strongly disagree' to 'strongly agree'] with each point scored from 1 to 5. The total connection to nature score calculated as a summation of individual item scores, ranging from 5 to 70, with higher scores indicating higher perceived connection to nature.

2.4.2. Physiological measures

Physiological measurements were obtained using an Empatica E4 wearable device, worn on participants' non-dominant wrist. Recent work has validated the use of Empatica E4 wearables as reliable indicators of electrocardiographic activity (Schuurmans et al., 2020). The real time physiological measures taken were as follows

1 Heart Rate (HR).
2 Heart Rate Variability (HRV).
3 Skin Temperature (ST).
4 Galvanic Skin Response (GSR), and
5 Photoplethysmography (PPG).

In the context of stress, 1–5 above are physiological measures of the sympathetic nervous system, which triggers an automatic physiological "fight-or-flight" response to a stressful event. A stress response results in increased HR (Greene et al., 2016), increased perspiration resulting in a directly proportional increase in skin conductivity as measured by GSR (Greene et al., 2016), and the restriction of blood flow to extremities, resulting in lower skin temperature (Herborn et al., 2015). Increase in blood pressure, which can be unobtrusively captured via PPG, is also a well-documented indicator of stress (Arza et al., 2019; Kok et al., 1995). The rise time of the PPG signal corresponds to speed at which the blood pressure spikes; higher rise time indicates lower stress (Sahni, 2012). Finally, low levels of HRV is widely regarded as a robust clinical marker of health deterioration and physical and mental stress (Dekker et al., 2000;

Taelman et al., 2009). Together, these five physiological measures used in this study can be interpreted to understand overall stress responses.

2.5. Statistical analyses

2.5.1. Within-subjects analysis

To address Research Question 1 we explored differences in psychological and physiological responses to warm, cool and control images across the entire study population.

2.5.1.1. Psychological outcomes. Change scores were generated for each of the three MACL measures for warm and cool colors and the control images by subtracting the baseline score for each measure from the post-condition score. We then used these scores in a series of repeated measures ANOVAs to determine statistically significant differences between stimuli condition. Positive values of hedonic tone and arousal change scores indicate increased positive mood and energy, respectively, whereas negative values in stress change scores indicate decreased stress, both shown as change from baseline. In addition, effect sizes for each comparison were calculated using partial eta squared. To determine inter-consistency of each of the MACL outcomes, we report the Cronbach's alpha (α) for each.

2.5.1.2. Physiological outcomes. While researchers have utilized these signals in a variety of ways, we focused on one measure per outcome of interest for this analysis. For HR, GSR, and ST, we calculated the mean value for each outcome from the data. For PPG, we calculated the rise time of the PPG signal (Sahni, 2012), which captures the heart's response during the diastole phase of the cardiac cycle (i.e. when the heart relaxes and allows blood to fill the ventricles). To capture HRV, we chose to calculate the standard deviation of NN intervals (SDNN), where a lower value indicates higher stress and vice versa (Shaffer and Ginsberg, 2017).

We segmented each of the physiological signals on the participant level using 30 second time windows with 50% overlap over the entire 2-minute recording per condition, as well as during the resting baseline. We then computed features which summarized the resulting segments and used mixed-effects models to ascertain differences in these measures between conditions. Due to their ability to account for the inherent dependency in longitudinal data, mixed-effects models were better suited for this task than traditional ANOVA and paired *t*-test methods. The mixed effects model used here compared each condition, using three contrasts: warm vs. cool, warm vs. control and cool vs. control.

2.5.2. Between subjects analysis

To address Research Question 2, we explored differences between the two study populations (USA and UK) on both psychological and physiological outcomes.

2.5.2.1. Demographic differences. We collected both age and gender information from our participants, as described in Section 2.1, and sought to determine if there were any statistically significant population demographic differences between our two participants groups. We used a Mann-Whitney U-Test to determine gender differences, a categorical outcome, and an independent *t*-test to determine age differences, a continuous outcome, between UK and USA participant groups.

2.5.2.2. Psychological outcomes. Change scores were generated for each of the three MACL measures for warm and cool colors and the control images by subtracting the baseline score for each measure from the post-condition score. Independent t-tests, using study location as the grouping variable, were used to understand statistically significant differences between these change scores. Positive values of hedonic tone and arousal change scores suggest increased positive mood and energy, respectively, whereas negative values in stress change scores suggest decreased stress, both shown as change from baseline. In addition, effect sizes for each comparison were calculated using Cohen's d, which is the mean difference divided by the pooled standard deviation of comparison scores.

2.5.2.3. Physiological outcomes. The physiological data was processed and segmented in the same manner as detailed in Section *Physiological outcomes* in Section 2.5.1, above. However, for the within-subjects analysis, the mixed effects model was amended to compare condition responses between locations. For example, heart rate between UK and US participants.

2.5.2.4. Connection to nature scale (CNS) analyses. In order to ascertain if trait level connection to nature, measured by the CNS, had a mediating effect on the relationship between the MACL outcomes and location (predictor), we ran a mediation model. Prior to running the model, we sought to determine inter-item reliability of the scale using Cronbach's alpha. Using the three MACL change scores (hedonic tone, stress and arousal) for both warm and cool colors from each study location, as well as CNS scores, we determined the relevant beta and beta standard error values from two regression models; the first using CNS as a dependent variable against location and the second using each MACL change score as the dependent variable against location and CNS. We then ran a Sobel test (Preacher and Hayes, 2004; Preacher and Hayes, 2008) to ascertain if CNS scores mediate the change scores by location.

3. Results

In this study 84 participants were recruited. Due to incomplete data sets, psychological data for 76 participants was analyzed (40 in the USA, 36 in the UK population) and physiological data for 70 participants (38 in the USA and 32 in the UK population).

3.1. Within subjects results

Our first analysis, to address Research Question 1, assessed differences between stimuli conditions across the entire study population; not accounting for participant location.

3.1.1. Psychological measurements

Repeated measures ANOVAs were used to ascertain differences between conditions on MACL outcomes across the total participant group. Cronbach's alpha outcomes showed acceptable to good inter-item consistency for the MACL outcomes of hedonic tone (α = 0.78), stress (α = 0.82) and arousal (α = 0.77). Mauchly's W test of sphericity was significant in the arousal condition, so sphericity is assumed in all other tests bar this. The Greenhouse Geisser correction was used to report adjusted degrees of freedom for the arousal outcome.

3.1.1.1. Hedonic tone change score. A repeated measures ANOVA showed a statistically significant difference in hedonic tone between warm, cool or control image post-assessment (F (2, 150) = 6.89, p = .001, partial η^2 = 0.084), as shown in Fig. 2. The Bonferonni post-hoc correction shows that both warm and cool color images showed increased hedonic tone when compared to the control images (p = .008 and 0.015, respectively). There were no statistically significant differences between hedonic tone between the warm and cool color images.

3.1.1.2. Stress change score. A repeated measures ANOVA showed no statistically significant difference in stress between warm, cool or control image post-assessment (F (2, 150) = 2.64, p = .075, partial η^2 = 0.034). While not significant at the p < .05 level, the result here approaches significance, therefore we explored the Bonferonni post-hoc correction which shows that stress in the cool color condition reduces

Table 1
Combined comparison of physiological responses between conditions.

	Warm vs. Cool	Warm vs. Control	Cool vs. Control
HR	β = −0.71 ± 0.57, p = .22	β = 0.56 ± 0.56, p = .31	**☐ = 1.27 ± 0.58, p = .03**
HRV	β = 4.76 ± 16.68, p = .78	**☐ = 36.43 ± 16.16, p = .02**	β = 31.67 ± 16.77, p = .06
ST	β = −0.04 ± 0.06, p = .47	β = −0.09 ± 0.06, p = .12	β = −0.05 ± 0.06, p = .42
GSR	**☐ = 0.05 ± 0.02, p = .01**	**☐ = −0.04 ± 0.02, p = .01**	**☐ = −0.09 ± 0.02, p < .001**
PPG	β = 0.13 ± 0.08, p = .12	β = 0.14 ± 0.08, p = .07	β = 0.02 ± 0.08, p = .84

Positive beta coefficients indicate that outcome measure is higher in the first condition of each column pair (i.e. Warm vs. Cool). Negative beta coefficients indicate the opposite. All significant results are in bold font. HR = Heart Rate; HRV = Heart Rate Variability; ST = Skin Temperature; GSR = Galvanic Skin Response; PPG = Photoplethysmography. Higher HR, ST and GSR indicate higher physiological arousal and/or stress; higher HRV and PPG indicates lower physiological stress.

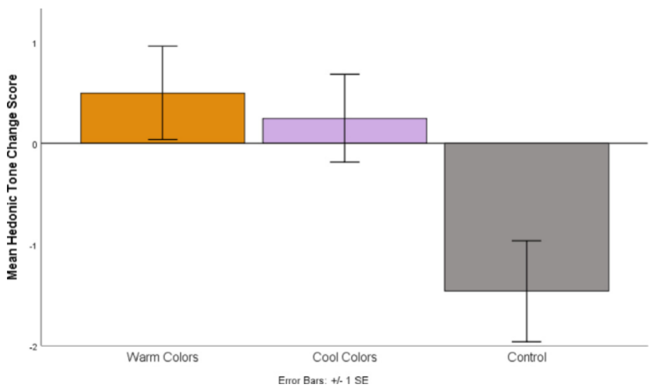

Fig. 2. MACL Hedonic Tone change score between warm, cool and control conditions across all study participants. A bar above zero indicates positive mood change.

more than that shown in the control condition (p = .06). There was no significant difference between color conditions on stress.

3.1.1.3. Arousal change score. A repeated measures ANOVA showed no statistically significant difference in arousal between warm, cool or control image post-assessment (F (1.75, 131.34) = 1.27, p = .285, partial η^2 = 0.017).

3.1.2. Physiological

The results for the physiological data are presented in Table 1. The mixed-effects models showed that mean Heart Rate (HR) was higher during the cool color image block than in control image blocks (β = 1.27, p = .03, 95% CI [0.14 2.40]), perhaps indicative of increased arousal. The mixed-effects models also showed that Heart Rate Variability (HRV) was higher during warm color image block as compared with the control image blocks (β = 36.43, p = .02, 95% CI (Roe et al., 2013; Gao et al., 2007; Karmanov and Hamel, 2008; Howarth et al., 2020)), suggesting that warm color images contributed to a restorative effect as measured by physiological stress response.

The mixed-effects models showed statistically significant changes in mean Galvanic Skin Response (GSR) between all three comparative scenarios. Specifically, the models indicated that mean GSR was higher during the warm color image block than during the cool color image block (β = 0.05, p = .01, 95% CI [0.01 0.08]), indicating higher stress in response to warm colors. The mixed-effects models also showed that mean GSR was lower during both the cool color image block (β = −0.09, p < .001, 95% CI [−0.12 −0.06]) and the warm color image block (β = −0.04, p = .01, 95% CI [−0.08 −0.01]) as compared with the control condition, indicating lower stress response during color conditions when compared to the control condition. The mixed-effects models did not show any statistically significant differences in mean ST or PPG rise time between the different conditions.

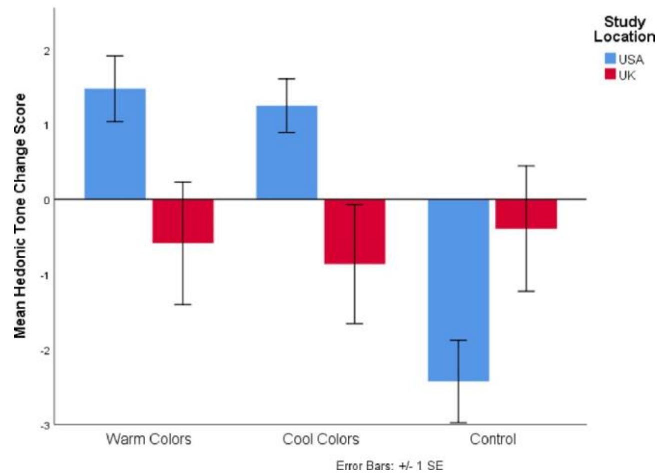

Fig. 3. MACL Hedonic Tone change score between study locations (USA and UK Participants). Positive scores indicate higher positive mood in post-condition assessment.

3.2. Between subjects results

Our second set of analyses determined differences between participant demographics as well as psychological and physiological outcomes between the two study locations; UK and USA.

3.2.1. Demographic differences

A Mann Whitney U-Test showed no significant differences between gender profiles between the two locations (U = 858, p = .944). When comparing age differences between UK participants (M = 25.1, SD = 4.70) and USA participants (M = 21.4, SD = 3.11), we see a statis- tically significant difference (Levene's test significant: t (57.23) = −4.15, p < .001, 95% CI [−5.55 −1.94]).

3.2.2. Psychological measurements

Independent t-tests were used to ascertain differences between locations on MACL outcomes. Levene's test of homogeneity of variance was significant in all hedonic tone outcomes as well as arousal in the cool colors condition, so equal variances are assumed in all tests bar these. Corrections were made where equal variances were not assumed by reporting adjusted degrees of freedom (Welch-Satterthwaite method).

Hedonic tone change score: Independent t-tests showed a statistically significant effect of geographical location (USA and UK participants) on hedonic tone between all three conditions: warm color (t (54.13) = 2.24, p = .03, 95% CI [.20 3.91], d = 0.51), cool color (t (48.87) = 2.43, p = .019, 95% CI [.36 3.86], d = 0.56) and control images (t (61.47) = 2.04, p = .046, 95% CI [−4.03 −0.04], d = 0.47). Fig. 3 shows the mean change scores plotted by location, indicating that, in the USA, hedonic tone significantly increases post-exposure to warm vs.

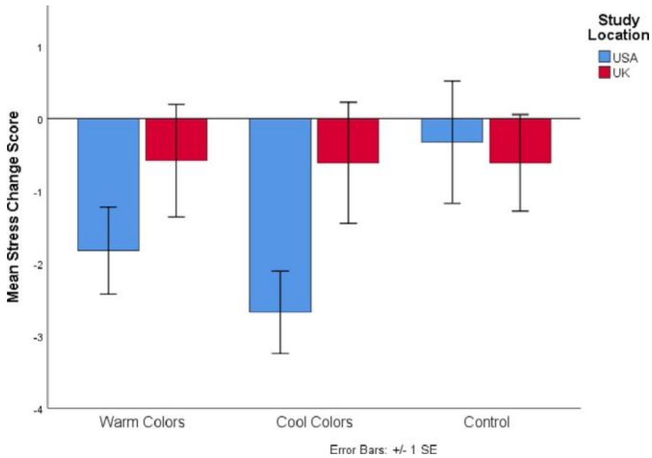

Fig. 4. MACL Stress change score between study locations (USA and UK Participants). Negative scores indicate reduced psychological stress in the post-condition assessment.

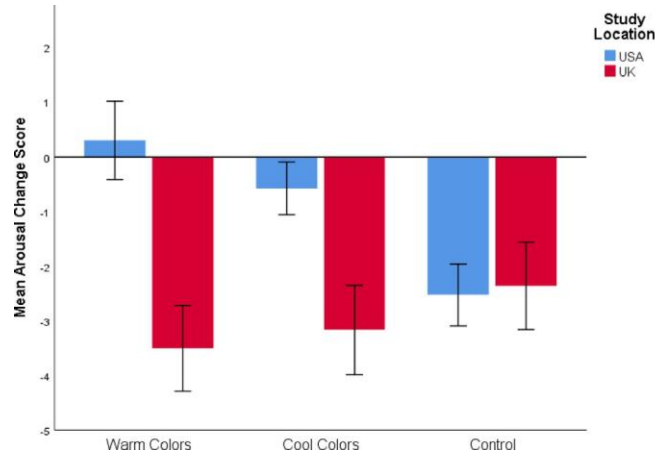

Fig. 5. MACL Arousal change score between study locations (USA and UK Participants). Positive scores indicate higher score in post-condition assessment.

cool color garden landscapes when compared to the UK, where hedonic tone scores significantly decrease post-test after viewing both warm and cool color conditions. In both groups, exposure to the control images reduced hedonic tone outcomes relative to baseline. Results suggest that exposure to the warm and cool color landscapes improved mood in US participants and decreased mood in the UK participants, supported by a moderate effect size.

Stress change score: The independent t-tests showed a statistically significant effect of geographical location on stress response in the cool color condition (t (74) = 2.08, p = .041, 95% CI [−4.04 −0.08], d = 0.29). The results suggest that post-test, participants in the US location showed significantly greater decrease in perceived stress to warm and cool color imagery as compared to UK participants, as shown in Fig. 4. There is only a small to moderate effect size of this result. Fig. 4 also shows that there were decreases in stress in both locations after all conditions, however there was no statistically significant effect of location on stress in the warm color (t (74) = 1.28, p = .21, 95% CI [−3.18 0.69] d = 0.47), or control images (t (74) = 0.26, p = .79, 95% CI [−1.89 2.46], d = 0.06).

Arousal change score: The independent t-tests showed a statistically significant effect of geographical location on arousal change scores in both the warm color (t (74) = 3.58, p = .001, 95% CI [1.69 5.92], d = 0.82) and cool color (t (57.58) = 2.73, p = .008, 95% CI [.69 4.49], d = 0.63) conditions. There was no significant effect of location on arousal on the control images (t (74) = 0.19, p = .86, 95% CI [−2.09 1.76], d = 0.64), as shown in Fig. 5. The two significant results suggest that both warm and cool colors decreased perceived feelings of arousal more in the UK sample than the USA sample, both supported by moderate to large effect sizes.

Connection to nature score (CNS): Cronbach's reliability analysis (α = 0.509) showed that the CNS items had poor inter-item reliability (Cortina, 1993). Subsequent Sobel tests showed no statistically significant impact of CNS on the relationships between any of the psychological outcomes and locations.

3.3. Physiological responses

We segmented each of the physiological signals on the participant level using 30 second time windows with 50% overlap over the entire 2-minute recording. We then computed features which summarized the resulting segments and used mixed-effects models to ascertain differences in these measures between locations. Due to their ability to account for the inherent dependency in longitudinal data, mixed-effects models were better suited for this task than traditional ANOVA and paired *t*-test methods. The overall physiological results between groups are presented in Table 2, and are discussed below.

3.3.1. Heart rate (HR). The mixed-effects models showed a statistically significant difference in mean HR between geographical locations across all three conditions: warm color (β = 3.77, p < .001, 95% CI [2.30 5.25]), cool color (β = 6.38, p < .001, 95% CI [3.84 8.93]) and control images (β = 2.29, p = .001, 95% CI [0.93 3.64]). The positive valence of the beta coefficients indicates that mean HR was higher in the US than in the UK, regardless of the experimental condition.

3.3.2. Heart rate variability (HRV). The mixed-effects models showed a statistically significant difference in HRV between geographical locations across all three conditions: warm color (β = −61.30, p = .02, 95% CI [−112.15 −10.45]), cool color (β = −55.98, p = .04, 95% CI [−109.28 −2.68]) and control images (β = −78.48, p = .001, 95% CI [−123.57 −33.40]). The negative valence of the beta coefficients indicates that HRV was higher in the UK than in the US, regardless of the experimental condition, suggesting lower stress in the UK location across all conditions. UK participants showed significantly higher HRV in the warm and cool color garden landscape and control images than the USA participants, suggesting reduced stress.

3.3.3. Skin temperature (ST). The mixed-effects models showed a statistically significant difference in mean ST between geographical locations across all three conditions: warm color (β = 0.56, p < .001, 95% CI [0.38 0.74]), cool color (β = 0.78, p < .001, 95% CI [0.56 0.99]) and control images (β = 0.58, p < .001, 95% CI [0.39 0.77]). The positive valence of the beta coefficients indicates that mean ST was higher in the US than in the UK, regardless of the experimental condition.

3.3.4. Galvanic skin response (GSR). The mixed-effects models showed a statistically significant difference in mean GSR between geographical locations across all three conditions: warm color (β = 0.11, p < .001, 95% CI [0.06 0.17]), cool color (β = 0.07, p = .01, 95% CI [0.02 0.12]) and control images (β = 0.15, p < .001, 95% CI [0.090 0.20]). The positive valence of the beta coefficients indicates that mean GSR was higher in the US than in the UK, regardless of the experimental condition.

3.3.5. Photoplethysmography (PPG). The mixed-effects models showed a statistically significant difference in PPG rise time between geographical locations during the warm color condition (β = 0.71, p < .001, 95% CI [0.45 0.97]). This suggests that participants in the US location experienced a significantly greater increase in PPG rise time to warm color

Table 2
Comparison of physiological responses between geographic locations.

	Warm	Control	Cool
HR	**□ = 3.77 ± 0.75, *p* < .001**	**□ = 2.29 ± 0.69, *p* < .001**	**□ = 6.38 ± 1.30, *p* < .001**
HRV	**□ = −61.30 ± 25.93, *p* = .02**	**□ = −78.48 ± 22.99, *p* < .001**	**□ = −55.98 ± 27.18, *p* = .04**
ST	**□ = 0.56 ± 0.09, *p* < .001**	**□ = 0.58 ± 0.10, *p* < .001**	**□ = 0.78 ± 0.11, *p* < .001**
GSR	**□ = 0.11 ± 0.03, *p* < .001**	**□ = 0.15 ± 0.03, *p* < .001**	**□ = 007 ± 0.03, *p* = .01**
PPG	**□ = 0.71 ± 0.13, *p* < .001**	β = −0.26 ± 0.14, *p* = .07	β = 0.06 ± 0.15, *p* = .69

Positive beta coefficients indicate that outcome measure is higher in the UK participants compare to the US participants. All significant results are in bold font. HR = Heart Rate; HRV = Heart Rate Variabil- ity; ST = Skin Temperature; GSR = Galvanic Skin Response; PPG = Photoplethysmography. Higher HR, ST and GSR indicate higher physiological arousal and/or stress; higher HRV and PPG indicates lower physiological stress.

imagery as compared to UK participants, as shown in Table 2. Since the rise time of the PPG signal corresponds to speed at which the participants' blood pressure spiked, this may indicate that participants in the US population responded more positively to warm color garden imagery than participants in the UK population. Table 2 also shows that PPG rise time was lower in the US in the control images ($\beta = -0.26$, $p = .07$, 95% CI [−0.53 0.2]) but higher in the cool color images ($\beta = 0.06$, $p = .69$, 95% CI [−0.23 0.35]). However, neither of these differences were statistically significant.

4. Discussion

For the first time, this study shows both psychological and physiological responses to warm and cool color images in a landscape garden setting, both across our entire population and with our between-location analysis, suggesting potential geographical differences between the USA and UK. Our within-subject analysis shows expected benefits to mood from exposure to the garden settings, consistent with restorative theory (Kaplan and Kaplan, 1989; Kaplan, 1995) and when compared to the control setting. We also see a trend towards decreased subjec- tive psychological stress in the cool colors condition compared with the control setting, also in keeping with previous research (Ulrich et al., 1991) supported by decreases in HR and GSR outcomes in the cool color condition.

Our between-subjects results are supported with color studies that show psychological differences across different geographical regions (Jonauskaite et al., 2019). Similar findings from a cross-cultural comparison study found differences in Japanese and Canadian visual fixation counts, suggesting cultural differences in processing different types of garden settings (Elsadek et al., 2019), although not in color. In our study, there were greater increases in subjective mood (i.e. hedonic tone and arousal) as well as reductions in subjective psychological stress from exposure to warm and cool color landscape garden in the USA group as compared with UK group. While the overall direction of change for stress and arousal are the same between locations for the color conditions, there are increases in hedonic tone in the USA group that are not seen in the UK group; with hedonic tone values being lower post color conditions exposure in this group. It could be that the novelty of the UK garden landscapes stimulated the US participants more than the UK participants, who are familiar with the stimuli. Further consideration needs to be made to understand the differences between hedonic tone in the US participants compared to the UK post-control condition given that the control stimuli was designed to be neutral in terms of both color and content.

As a secondary result, the role of trait level connection to nature as a mediator in the relationship between the study location and psychological outcomes did not seem to account for any implied location specific difference on MACL outcomes. While nature connectedness may be an important mediator in the restorative effects of nature exposure as compared to an urban control (Mayer et al., 2009), we show that this trait is not significant when comparing warm or cool colored garden settings. In addition, our reliability analyses suggested that the CNS was not sufficiently reliable in this sample, so further research is required to further understand this effect.

The physiological results also show statistically significant differences between geographic locations in response to viewing warm and cool color landscapes. Specifically, heart rate, skin temperature and GSR levels were higher in the USA group when compared with the UK group, suggesting higher arousal in the USA group. This is further supported by the psychological outcomes that suggest higher levels of arousal in the USA group when compared to the UK group. To our knowledge, there are no other studies that show physiological measured differences between geographic locations in response to viewing warm and cool color landscapes. Our findings suggest that future color studies and color studies of landscape gardens across geographical locations would benefit from including both psychological and physiological measurements.

However, the higher levels of HRV in the UK group suggests that the garden landscapes led to lower physiological stress levels (Healey and Picard, 2005) relative to the US group. This is the opposite of the psychological results which show reductions in psychological stress in both conditions, with a greater stress reduction in the US group. There are several possible explanations for this discrepancy, which we discuss in detail below. But first, it should be noted that psychological and physiological stress responses do not necessarily align (Stigsdotter et al., 2017), especially under short time frames as employed in this experiment where responses were measured after 2 min of exposure to stimuli. This may be due to mediating factors in the association between psychological and physiological stress responses such as behavioral pathways (medication, caffeine intake), while an individual's integrated stress response also depends on chronic psychological factors that could lead to different acute stress responsivities (Chida and Hamer, 2008).

Hedonic tone theories shows the connection between arousal and biological responses (Berlyne, 1971) that may be applicable to the results we have presented here. Hedonic values are intimately associated with how arousing a stimulus is, with the arousal model proposing that a reduction in high arousal and a modest increase in low arousal may be experienced as pleasant (Berlyne, 1971; Küller et al., 2009). If the levels of complexity or novelty of a stimulus increase, the primary reward system becomes increasingly active, generating positive experiences and pleasantness. In turn, if complexity or novelty continues to increase, an activity is created in the aversion system, generating an unpleasant experience. This can be better visualized as an inverted-U function, with aesthetic pleasure as a consequence of increased activation in levels of arousal, and a reduction in pleasantness if the level of arousal increases too much (Berlyne, 1971). One possible explanation for the results presented here is that participants of the two geographic locations may be at different points of the inverted U-function; with the USA population showing increases in levels of hedonic tone and decreases in stress that are not shown in the UK population, further reflected in the physiological outcomes where GSR levels are higher in the USA population compared to the UK population, perhaps suggesting. different aesthetic responses to the stimuli.

Research into perceptions of color by geographical location suggest that there are differences in color preferences between cultural locations (Aslam, 2006). Preference studies on tree canopies show preferences for red colors in an African context compared to purples and oranges (Kaufman and Lohr, 2004), and for red colors in New Guinea compared to green (Berghage and Wolnick, 2000). While these stud- ies suggest culture specific color preferences, others have shown that cultural background may have little impact on color-emotion responses (Eysenck, 1941; Gao et al., 2007). There appears to be little evidence to suggest stress physiology changes as a result of a cultural based color preference. As far as we are aware this is the first time that this has been reported in our study.

The differences between the two locations could relate to the images used; typically British flowers/plantings of warm and cool colors. The USA population may be showing increases in arousal in both the cool and warm colors because the stimuli is unfamiliar and novel to them (Weierich et al., 2010), further explaining why there was limited reaction to these images in the UK. An alternative explanation may point to a cultural difference between the two locations. This study was conducted in the American Fall, which has associations with Thanksgiving as well as an abundance of yellows and oranges in local Virginia flora. Previous research has suggested changes in color preference with seasonality (Kuper, 2020; Paddle and Gilliland, 2016; Schloss and Heck, 2017), so the physiological benefits shown in the warm color condition in the USA population (i.e. improved hedonic tone) may be reflective of this. Further research is required to address this specifically.

However, both positive ("happy" or "peaceful") and negative ("threatening" or "saddening") stimuli can result in an increase in arousal reflected by increases in GSR (Kasos et al., 2018), suggesting GSR signal is not representative of the type of emotion, but of its inten- sity. So perhaps the novelty of the plantings is responsible for the GSR changes we have seen in this study in the USA population. However, this deviates from the theory that green space generally has psychologically restorative properties in Western populations (Kaplan and Kaplan, 1989; Kaplan, 1995) suggesting it's important to look at landscape color be- yond what is 'green'.

While we show potential geographical differences here, in both psychological and physiological responses to color, both samples are located in the Global North and are Anglophone. It is unlikely the two samples are so far culturally removed from each other that this alone accounts for the differences in outcomes. While our demographic sample significantly differ in age, we do not believe a mean age difference of 3.7 years should impact perception of color. Color vision does alter with age, as the number of retinal ganglion cells decreases and the retinal topography changes, with chromatic sensitivity becoming an important factor above 40 years of age (Barbur and Rodriguez-Carmona, 2015). The participants in our sample were less than 35 years of age, so further investigation is needed into other geographical differences that might explain these findings. We suggest this protocol is applied across other demographics to explore the explicit cultural differences in color preference (and other aesthetic perceptions of space) and their role in stress regulation. The results of this study are useful for garden and landscape architects who may choose to optimize their planting schemes and color palettes to suit the emotional needs of their users. Color choice can have both psychological and physiological outcomes and is not a choice that should be necessarily be left to the simple preference of the designer.

This study used images of relatively formal garden landscapes, but there is research suggesting that more natural, less formal garden landscapes could potentially contribute to increased restorative potential (Twedt et al., 2016). It has also been suggested that foliage, flower sizes, leaf width, fragrance, symmetry and nativeness can also contribute to differences in preferences for green spaces (Hůla and Flegr, 2016). Studying these variables in future studies would enable findings to be used in order to optimally plan and tailor private and public green spaces for their users.

There are limitations to this study that would need consideration in future replications of this protocol. Specifically, future research should ensure that – in the event of cross-site testing – there is adequate calibration of the testing spaces. While we attempted to replicate as much as possible between sites, we did not formalize exact distances from the computer screen, levels of lighting in the room (including luminosity) and screen profiles. This means that color fidelity may have been lacking across testing monitors or the results may have been influenced by differences in screen brightness.

Beyond this, the use of a slideshow does not afford a high enough level of ecological validity to allow findings to be applied to design landscape spaces. Future studies may wish to use video stimuli that offers a 'walking' experience which could be used to recreate a garden experience, or capture real-world exposure to color. Furthermore, the incorporation of other sensory elements would be needed to fully understand the differences between warm and cool colored spaces on psychological and physiological stress. While our research starts this important narrative, it is limited by only using visual stimuli on computer screens. This study used images of relatively formal garden landscapes but there is research suggesting that more natural, less formal garden landscapes could potentially contribute to increased restorative potential (Twedt et al., 2016). It has also been suggested that foliage, flower sizes, leaf width, fragrance, symmetry and nativeness can also contribute to differences in preferences for green spaces (Hůla and Flegr, 2016). Studying these variables in future studies would enable findings to be used in order to optimally plan and tailor private and public green spaces for their users.

5. Conclusion

We show, for the first time, research attempting to understand the role of color in designed green spaces and their potential benefit on both psychological and physiological outcomes in two geographic locations. There appears be psychological benefits on mood and stress from viewing landscape garden settings, with a more pronounced effect in the USA participants. However, the physiological results suggest the USA group showed higher stress responses than those in the UK group. There results suggest location-specific differences in both psychological and physiological responses to color that were not expected but warrant further investigation.

Declaration of Competing Interest

None.

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Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.wss.2021.100038.

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