Urban Forestry & Urban Greening 59 (2021) 126974

Contents lists available at ScienceDirect

Urban Forestry & Urban Greening

journal homepage: www.elsevier.com/locate/ufug

# The relationship between surrounding greenness, stress and memory

Claudia Lega [a,*], Christopher Gidlow [a], Marc Jones [b], Naomi Ellis [a], Gemma Hurst [a]

[a] Centre for Health and Development (CHAD), Staffordshire University, Stoke-on-Trent, United Kingdom
[b] Department of Psychology, Manchester Metropolitan University, Manchester, United Kingdom

ARTICLE INFO

Handling Editor: Matilda van den Bosch

*Keywords:*
Memory
Mediation
Natural environments
Stress

ABSTRACT

Evidence suggests that surrounding greenness is associated with multiple health-related benefits, including better cognitive functioning. Underlying mechanisms of the relationship between exposure to natural environments and cognitive functioning have not been widely researched. This study aimed to analyse the relationship between surrounding greenness and memory performance, and to explore the potential mediating role of stress. A sample of 185 adults was recruited in Stoke-on-Trent and Newcastle-under-Lyme (UK). Data were collected on exposure to and use of natural environments, stress, three measures of memory performance (short-term memory, working memory, overall memory), and participant socio-demographics. Linear univariate regression was conducted to investigate the relationship between surrounding greenness, memory performance and stress. Mediation analysis was conducted to investigate the role of stress as mediator of the relationship between surrounding greenness and memory performance. Surrounding greenness was significantly associated with better short-term and overall memory performance and lower levels of stress, and lower levels of stress were significantly associated with better short-term and overall memory performance. Stress was a significant partial mediator of the relationship between surrounding greenness and short-term memory. Results were robust to controls for area deprivation. One explanation for these findings is that stress is a multifaceted reaction to a demand which involves cognitive functioning, so that less stress might lead to improved cognition. These results suggest that cognitive benefits of exposure to surrounding greenness are partially mediated by lower levels of stress. Future research should consider other potential mediators of the relationships between surrounding greenness and cognitive functioning, such as mood, well-being and social relationships.

## 1. Introduction

There is evidence that exposure to natural environments is associated with positive health-related outcomes, such as better physical health (Browning and Lee, 2017), mental health (Van Den Berg et al., 2015), and self-reported general health (Orban et al., 2017; Reid et al., 2018). Some of these studies showed the benefits of exposure to natural environments in the neighbourhood, called surrounding greenness (Balseviciene et al., 2014; Triguero-Mas et al., 2017; Zijlema et al., 2019). Surrounding greenness is a commonly used indicator that uses satellite imagery to reflect the amount of natural environments in the neighbourhood area. One explanation for the benefits of exposure to natural environments is proposed by the Attention Restoration Theory (Kaplan and Kaplan, 1989), which states that contact with nature can restore directed attention, the conscious process of focusing on a selected stimulus while avoiding distractions (Bratman et al., 2012). According to Kaplan, natural environments present intrinsic components, such as fascination and compatibility, that effortlessly capture attention and allow directed attention to replenish. Alongside Attention Restoration Theory, Stress Reduction Theory (Ulrich, 1981) describes the affective and aesthetic response associated with exposure to natural environments (rather than cognitive processes) which includes preference for natural environments, increased positive mood and emotions, reduced stress and physiological conditions related to stress such as heart rate, muscle tension and blood pressure. Attention Restoration Theory has been typically explored by measuring changes in cognitive functioning following exposure to natural environments (Ohly et al., 2016), while Stress Reduction Theory has been supported by evidence of stress reduction in response to natural environments (Van den Berg et al., 2010; Ward Thompson et al., 2016).

Exposure to natural environments is associated with better cognitive functions. Cognitive functioning is a broad term that includes different cognitive processes involved in the elaboration of information, such as attention (the act of focusing on selected stimuli and avoid distractors),

* Corresponding author at: Staffordshire University, School of Life Sciences and Education, Leek Road, ST4 2DF, Stoke-on-Trent, United Kingdom.
*E-mail address:* claudia.lega@research.staffs.ac.uk (C. Lega).

https://doi.org/10.1016/j.ufug.2020.126974
Received 3 April 2020; Received in revised form 7 November 2020; Accepted 24 December 2020
Available online 2 January 2021

memory (the capacity to store and recall information), and reasoning (the ability to think through, form links between thoughts, and make judgements). This relationship has been investigated by cross-sectional (Kuo, 2001), laboratory (Mayer et al., 2009), and field studies (Johansson et al., 2011). The beneficial effect of natural exposure has been found for different processes of cognitive functioning such as attention (Berto, 2005), memory (Perkins et al., 2011) and vigilance (Rich, 2008). Some studies exploring cognitive functioning have compared responses to natural and urban environments (Berman et al., 2012; Gidlow et al., 2016a; Laumann et al., 2003). Others have explored cognitive functioning in different types of natural environments exposure, such as walking in a natural environment (Shin, Shin et al., 2011), looking at natural environments through a window (Tennessen and Cimprich, 1995), and looking at pictures (Berman et al., 2008) or videos (van den Berg et al., 2003) representing a natural environment.

However, recent systematic reviews on exposure to natural environments and cognitive functioning have highlighted some gaps in the measurement of cognitive functioning. De Keijzer et al. (2016) recommended future studies to use objective measures of cognitive functioning, such as computerised tests and tasks conducted by professionals, as they provide an unbiased assessment of performance and so are more reliable than subjective measures (e.g., information self-reported by participants on memory ability). A recent systematic review reported some uncertainty regarding which cognitive outcomes are most improved by exposure to natural environments, since some studies reported a significant effect on tasks involving working memory but no significant effects for tasks measuring vigilance, and advised to reach consensus on the most appropriate cognitive measures (Ohly et al., 2016). In another study, exposure to natural environments had a significant positive effect on working memory, attentional control and cognitive flexibility, with low to moderate effect sizes, and the use of actual, rather than virtual, exposure to natural environments was suggested to provide a stronger and more reliable effect (Stevenson et al., 2018). Taken together, these studies highlight the need to understand exactly what the cognitive benefits of exposure to natural environments are, through the use of specific cognitive measures.

Despite the number of studies showing the relationship between natural environments and cognitive functioning, pathways underlying this relationship are less studied. One study tested seven potential mediators (physical activity, social interaction with neighbours, loneliness, neighbourhood social cohesion, perceived mental health, traffic noise and worry about air pollution) of the relationship between natural environments and cognitive functioning (Zijlema et al., 2017). Distance to natural environments was positively related to completion time of a cognitive task (i.e., as distance to natural environment from the home increased, cognitive performance reduced) but none of the mediators were significant. Another study examined the effect of exposure to natural environments at home, school and on the route between the two, on cognitive development of children (Dadvand et al., 2015). Authors observed enhanced 12-month progress in working memory and superior working memory, and a reduction in inattentiveness, associated with greenness within and surrounding school. Indoor levels of elemental carbon (used as a measure of air pollution) explained 20–65 % of the association between natural environments within/surrounding school and cognitive functioning. Moreover, accounting for elemental carbon made the association between natural environments surrounding school and superior working memory, as well as the association between natural environments within/surrounding school and inattentiveness, not significant. However, a more recent study found that physical activity, air pollution and social support did not significantly mediate the association between surrounding greenness and a global cognition score evaluating reasoning, phonemic and semantic verbal fluency and short-term memory (De Keijzer et al., 2018). Finally, other aspects related to cognitive functioning have been explored. For example, connectedness to nature was a significant mediator of the relationship between a short exposure to natural environments (a 10-minute walk) and ability to think through a personal problem (Mayer et al., 2009). Therefore, there is some mixed evidence for pathways through which natural environments might influence cognitive functioning, and further research on these pathways, using mediation analysis, has been recommended (de Keijzer et al., 2016).

Other outcomes of the exposure to natural environments studied include stress (Hazer et al., 2018). A systematic review explored stress as a consequence of exposure to real-time non-laboratory natural environments, such as outdoor walk and nature viewing (Kondo et al., 2018). Thirty-one stress indicators were identified, twenty-six of which objective (physiological indicators such as saliva, blood and urine) and five self-reported (questionnaires evaluating perceived stress, restoration, and other psychological aspects).The review concluded that heart rate, blood pressure and self-reports provide the most convincing support for the hypothesis that exposure to outdoor environments reduces stress. All reviewed studies measured markers of acute stress, i.e., the immediate change occurring in response to exposure to natural environments, as opposed to chronic stress, such as an ongoing condition with enduring impact (Hammen et al., 2009). However, other studies found a positive association between surrounding greenness and indices of chronic stress such as hair cortisol (Gidlow et al., 2016b) and allostatic load (Egorov et al., 2017), suggesting that exposure to natural environments benefits stress also in the long term, and that different types of exposure confer different outcomes.

Stress is also associated with cognitive functioning, as it has been found to negatively affect memory performance (Kuhlmann, 2005), but also to be associated with reduced memory performance in an inverted U-shaped manner, where moderate salivary cortisol levels are associated with better memory recall (Schilling et al., 2013). A review on this topic categorised stress and memory according to several characteristics, such as stress duration and memory phase (Sandi, 2013). It proposed a model where intense chronic stress that is not related to a task impairs explicit memory (i.e., facts and personal experiences) during the phase of retrieval, while acute stress of medium intensity and linked to a task mainly enhances implicit memory (i.e., procedures and skills) during the phase of consolidation. This also seems to be supported by physiological studies showing that glucocorticoids (hormones secreted after a stressful event) impair memory retrieval and working memory, but enhance memory consolidation (Roozendaal, 2002). Therefore, literature on this topic suggests that the relationship between stress and memory may depend on the type of stress and memory considered.

Evidence on associations between exposure to natural environments and stress, and between stress and cognitive functioning, raises the possibility that stress acts as a link between the exposure to natural environments and cognitive functioning. Some studies have used self-reported stress as a mediator of the relationship between exposure to natural environments and other outcomes. Stress, measured by the Perceived Stress Scale, was a full mediator of the relationship between self-reported quantity of greenery and mental health (De Vries et al., 2013). Negative affect, measured by the Depression, Anxiety and Stress Scale, mediated the relationships between access to gardens, allotments and views of greenspace and strength and frequency of cravings for food and other substances (Martin et al., 2019). Restoring capacities, including stress recovery, is proposed to be one of the potential pathways between exposure to natural environments and health (Markevych et al., 2017), although only two studies have been conducted on the topic (De Vries et al., 2013; Kuo, 2001). However, one study found that stress did not mediate the relationship between surrounding greenness and well-being (Liu et al., 2019), and another found that stress did not mediate the relationship between surrounding greenness and life functioning, measured by the Ineffective Management of Major Issues Scale (Kuo, 2001). These mixed results suggest that stress might be a mediator between exposure to natural environments and certain outcomes, although there is a lack of studies exploring this link (Markevych et al., 2017), and a variety of measures have been used to assess the type of exposure and the outcomes.

This study focused on the effects of exposure to natural environments in the neighbourhood beyond the intentional contact with them through visits. Types of interaction with natural environments have been classified as: indirect, which is experiencing natural environments while not being physically present in them, such as when viewing nature through a window or in a picture; incidental, which refers to encountering natural environments as a by-product of another activity, such as while commuting to work or indoor; intentional, which includes a deliberate contact, such as recreational visits (Keniger et al., 2013). The effects of these different exposures on health and well-being have been compared, with mixed results (Garrett et al., 2019; Martin et al., 2020). Zijlema et al. (2017) found a significant association between residential distance to natural environments and time required for completing a cognitive task, when controlling for time spent away from home, and another study found that vegetation cover in the neighbourhood was associated with a lower prevalence of depression, anxiety and stress, when controlling for time spent outdoor (Cox et al., 2017). Therefore, there is evidence that different types of exposure to natural environments are associated with different psychological effects, and that exposure to surrounding greenness alone might be enough to provide some benefits.

Overall, the literature suggests that exposure to natural environments is associated with certain aspects of cognitive functioning. However, pathways underlying this relationship are not well understood and the use of specific cognitive measures has been recommended. Among the factors suggested as potential pathways, stress was found to significantly mediate the relationship between exposure to natural environments and some health-related outcomes. The present study builds on the existing work by being the first cross-sectional study investigating the relationship between exposure to surrounding greenness (as opposed to a short-term exposure, such as a walk in a natural environment) and memory performance in an adult population, using objective measures of both environment and memory. This study used a cross-sectional design to explore the association between exposure to surrounding greenness and cognitive functioning, and the potential mediating role of stress.

The aims were:

1. To analyse the relationship between surrounding greenness, memory performance, and stress
2. To explore the potential mediating role of stress in the relationship between surrounding greenness and memory performance.

## 2. Method

### 2.1. Participants and procedures

A sample of adults (aged $\geq$18 yr) was recruited in Stoke-on-Trent and Newcastle-under-Lyme (United Kingdom) between June 2016 and October 2017. Stoke-on-Trent has a population of 363,421 inhabitants, an area of 304 $km^2$, and natural environments (urban green space, non-urban green space and blue space) cover 22,590 ha (Smith et al., 2017). Newcastle-under-Lyme has a population of 129,490 people (Office for National Statistics, 2018), it covers area of 211 $km^2$, and has a total of 8.16 ha of greenspace (including parks and gardens amenity green space and accessible natural greenspace) per 1,000 people (Green Space Strategy, 2018).

Participants were contacted via post, flyers in the University premises, presentations in class, e-mails and word of mouth, using an opportunistic sampling method. A list of addresses of people who took part in previous studies and agreed to be contacted was used. Participants who expressed their interest to take part were asked to complete a brief screening survey to determine eligibility. Inclusion criteria were: aged at least 18 years, living in the Stoke-on-Trent or Newcastle-under-Lyme, and being a fluent English speaker. An appointment was made to meet participants either at University or their home. This lasted approximately 30 min, and involved self-administered surveys and the completion of cognitive tasks (detailed below). Participants were given a £10 retail voucher in appreciation of their time.

### 2.2. Measures

Participant surveys included questions on socio-demographics (including home postcode), frequency of visits to natural environments and stress. After the survey, two memory tasks were verbally administered.

#### 2.2.1. Socio-demographic information

- Gender
- Age
- Educational level. Single item question with five response categories: no formal qualification, GSCE/equivalent, A-level/equivalent, degree level/equivalent/higher, other. This was included in the analyses as a categorical (nominal) variable.
- Index of Multiple Deprivation (IMD). Official measure of relative deprivation for small areas in England. It combines information from seven domains (income deprivation; employment deprivation; education, skills and training deprivation; health deprivation and disability; crime; barriers to housing and services; living environment deprivation). It categorises small areas in deciles, where 1 stands for the 10 % most deprived neighbourhood. Data was available from https://www.gov.uk/government/statistics/english-indices-of-deprivation-2015 (Department for Communities and Local Government, 2015).

#### 2.2.2. Use of natural environments

- Frequency of visits to natural environments was measured as number of visits to natural environments over the past four weeks, with five response categories: never, once, two or three times, one to four times weekly, (almost) daily.

#### 2.2.3. Stress

- Perceived Stress Scale (PSS) – a self-report questionnaire developed by Cohen et al. (1983) was used to evaluate perception of stress over the past four weeks. This has been developed and used as a measure of chronic stress (Cohen et al., 1983; Liston et al., 2009; Tomiyama et al., 2011; Yuan et al., 2016). Ten items investigate both negative ("how often have you felt upset?") and positive feelings ("how often have you felt confident?"), using a 4-point Likert scale going from 0 (never) to 4 (very often). Total score ranges from 0 to 40 where higher scores indicate higher levels of stress.

#### 2.2.4. Memory performance

After the survey, two memory tasks were administered (Forward Digit Span and Backward Digit Span), and a third memory score was obtained from the composite score of the two tasks.

- Forward Digit Span (FDS; Wechsler, 1997) – Participants were verbally presented series of random digits and asked to recall them in the same order immediately after. The task started with two digits and increased of one digit every two series correctly recalled, up to 9 digits, for a total of 16 series. After two consecutive mistakes in two equally long series, the task was stopped. The score is the number of series correctly recalled (range from 0 to 16). This task has been used as a measure of short-term memory (Bull et al., 2008; Conway 2002) as it requires the basic storage of information for a limited period of time.
- Backward Digit Span (BDS; Wechsler, 1997) – The procedure was the same as described for the FDS task, but here participants were asked to recall the digits in reverse order. The task went up to 8 digits to

recall backwards, with 14 series in total. The score is the number of series correctly recalled (range from 0 to 14). This task has been used before as measure of working memory, which involves the manipulation of information prior to recalling (Bull et al., 2008; Jaeggi et al., 2010).

- Total Digit Span (TDS; Tulsky et al., 2003) – The sum of the FDS and BDS scores gave an overall score that could range from 0 to 28. This score has been used previously as a measure of overall performance on digit span capacity and can be compared to normative data (Myerson et al., 2003; Pisoni et al., 2011).

#### 2.2.5. Exposure to natural environments

Surrounding greenness was measured using the Normalized Difference Vegetation Index [NDVI, (Weier and Herring, 2000)], an index of natural environments in the neighbourhood determined using the Geographical Information System (GIS) and obtained from the postcode of the participant and its corresponding Lower Super Output Area (LSOA). It is based on visible (red) and non-visible (near-infrared) lights, and it ranges from -1 to +1 where higher values indicate higher greenness. NDVI has been described as an indicator of green space availability and it has been deemed relevant when evaluating surrounding greenness and its related psychological processes (WHO Regional Office for Europe, 2016). Images for this study were derived from Landsat 8 satellite, at 30m × 30m spatial resolution, and were gathered from May to September between 2011 and 2013 as this is the greenest season (Smith et al., 2017). NDVI was calculated within a 400-metre buffer around the household, which corresponds to a walk of approximately five minutes, since this was used as a measure of walkable neighbourhood area in other studies (Boehmer et al., 2006; Hoehner et al., 2005; Smith et al., 2010).

### 2.3. Statistical analysis

The target sample size was 200.This was based on: an estimated 150–200 participants required to detect a small effect, using a mediation analysis, power of 0.8 and an alpha level of 0.05. Previous studies found a small (Mears et al., 2019) and a small to medium (Kardan et al., 2015) effect size when investigating the association between natural environments metrics and health-related outcomes.

Descriptive statistics were calculated for the total sample. The Kolmogorov-Smirnov test of normality was carried out to identify whether variables were normally and non-normally distributed. Correlations and difference tests were run to identify covariates. Pearson's correlation and Analysis of Variance (ANOVA) were used with normally distributed variables. Spearman's correlation and Kruskal-Wallis were used with non-normally distributed variables. The Index of Multiple Deprivation was included as covariate as a measure of deprivation, while gender was included as literature supported its role on memory (Lynn and Irwing, 2008) and stress (Matud, 2004). Mediation analysis was undertaken in four steps following the procedure suggested by Baron and Kenny (1986):

1) Association between predictor (surrounding greenness) and outcomes (FDS, BDS, TDS)

2) Association between predictor and potential mediator (stress)

3) Association between potential mediator and outcomes

4) Association between predictor and outcome through the potential mediator

Each step was explored with linear univariate regression, and outcomes and mediators were tested individually in separate models. Models were adjusted for covariates, and a bootstrapping method was used to estimate a population sampling. The mediation was partial if both direct (predictor on outcome) and indirect (predictor on outcome through mediator) effects were significant. A mediation was full if only the indirect effect was significant (Field, 2009).

## 3. Results

### 3.1. Population recruitment and characteristics

In total, 4,701 letters and around 30 e-mails were sent to recruit participants. The response rate for the letters was approximately 2%. Complete data were obtained for 185 adults, 89 of which (49.4 %) recruited via post, 44 (24.4 %) via e-mails and words of mouth, 26 (14.4 %) via presentation in class and 21 (11.7 %) via flyers. The sample was composed by more women than men, with a mean age of 42.21 [±18.79, range 18–91 (Table 1)]. Age distribution is presented in Fig. 1. Eighty-nine participants were recruited via post (49.4 %), while 91 were recruited with e-mails and flyers (50.6 %). The majority of the sample had a formal qualification (86.1 %), which was either GSCE (13.3 %), A-level (37.2 %) or a degree (35.6 %). More than half of participants (64 %) came from the first five most deprived areas.

The NDVI in the 400-metre buffer ranged from 0.31 to 0.72 (Fig. 2). Twenty participants never visited natural environments in the past month (11.1 %), while 32 visited them almost daily (17.8 %). The mean scores for the memory tasks were 10.06 for the FDS (corresponding to 6 correctly recalled digits), 6.87 for the BDS (4-digits correctly recalled), and 16.93 for the TDS. Scores were not compared to normative data as the sample was heterogeneous in terms of age. On a total scale from 0 to 40, the average score of the PSS was 16.85, which indicated that the sample had slightly higher than average levels of perceived stress (normal range 12.0–14.2; Cohen, 1994).

### 3.2. Identification of covariates

The results of the Kolmogorov-Smirnov test of normality were significant for age (showing that this variable was non-normally distributed), but not for FDS score, BDS score, TDS score, stress and frequency of visits to natural environments (indicating normal distribution).

There was a weak correlation between age and stress, frequency of visits to natural environments and BDS score, frequency of visits to natural environments and TDS score. There was a significant moderate correlation between frequency of visits to natural environments and FDS score, and between frequency of visits to natural environments and stress. Results are reported in Table 2. These were then included as covariates in subsequent analyses, together with gender and deprivation which were identified a priori.

### 3.3. Associations between surrounding greenness and memory performance

A linear regression, adjusted for gender, age, educational level, deprivation and frequency of visits to natural environments, showed that surrounding greenness was significantly and positively associated with FDS ($\beta = .45$, 95 % CI = 12.59, 21.10, $p < .001$), and TDS ($\beta = .34$, 95 % CI = 10.50, 26.12, $p < .001$), but not with BDS ($\beta = .13$, 95 % CI = -.83, 7.73, $p = .11$). Full tables of results are reported in the Supplementary Material.

### 3.4. Associations between surrounding greenness and stress

A linear univariate regression showed that surrounding greenness was significantly and negatively associated with stress ($\beta = -.18$, 95 % CI = -32.02, -1.21, $p = .04$), when covariates (gender, age, educational level, deprivation, and frequency of visits to natural environments) were included in the model. Full tables of results are reported in the Supplementary Material.

### 3.5. Associations between stress and memory performance

A linear univariate regression showed that stress was significantly and negatively associated with FDS ($\beta = -.23$, 95 % CI = -.14, -.03, $p$

**Table 1**
Characteristics of study population (N = 185).

| | | | FREQUENCY (%) | MEAN (SD) RANGE |
|---|---|---|---|---|
| Socio-demographic information | Gender | Male | 77 (41.6) | |
| | | Female | 108 (58.4) | |
| | Age | | | 42.21 (18.79)<br>18 – 91 |
| | Educational level | No formal qualification | 17 (9.4) | |
| | | GSCE / O-level / equivalent | 24 (13.3) | |
| | | A-level / equivalent | 67 (37.2) | |
| | | Degree / equivalent / higher | 64 (35.6) | |
| | | Other | 8 (4.4) | |
| | Index of Multiple Deprivation | 1 (Most deprived) | 19 (10.8) | |
| | | 2 | 29 (16.5) | |
| | | 3 | 31 (17.6) | |
| | | 4 | 24 (13.6) | |
| | | 5 | 16 (9.1) | |
| | | 6 | 15 (8.5) | |
| | | 7 | 17 (9.7) | |
| | | 8 | 14 (8.0) | |
| | | 9 | 7 (4.0) | |
| | | 10 (Least deprived) | 4 (2.3) | |
| Exposure to natural environments | NDVI 400 m | | | 0.46 (0.09)<br>0.31 – 0.72 |
| | Frequency of visits to natural environments | Never | 20 (11.1) | |
| | | Once in the past month | 32 (17.8) | |
| | | Two or three times in the past month | 50 (27.8) | |
| | | One to four times weekly | 45 (25.0) | |
| | | Almost daily | 32 (17.8) | |
| Memory | FDS | | | 10.06 (2.97)<br>2 – 16 |
| | BDS | | | 6.87 (2.54)<br>2 – 14 |
| | TDS | | | 16.93 (4.88)<br>6 – 28 |
| Stress | PSS | | | 16.85 (8.30)<br>0 – 40 |

FDS = Forward Digit Span; BDS = Backward Digit Span; TDS = Total Digit Span; PSS = Perceived Stress Scale.

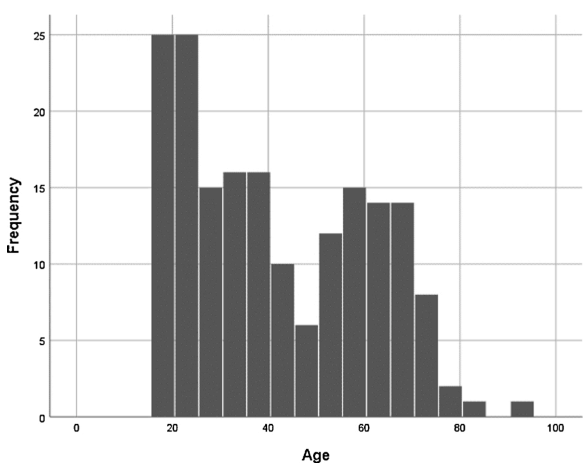


**Fig. 1.** Distribution of age (M = 41,21, SD = 18.79, range 18-91).

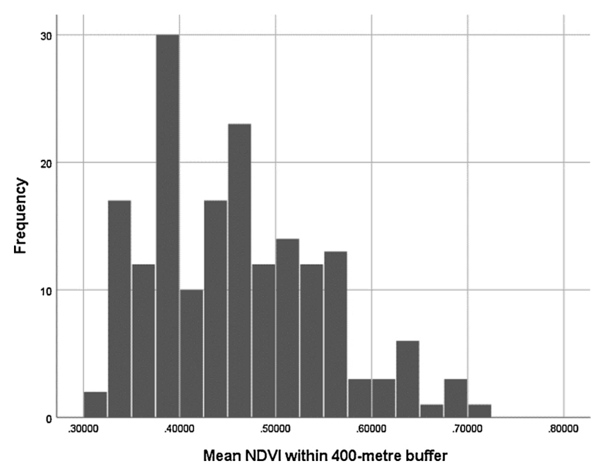


**Fig. 2.** Distribution of NDVI within a 400-metre buffer around the household (M = 0.46, SD = 0.09, range 0.31 – 0.72).

=.003) and TDS (β = -.18, 95 % CI = -.19, -.02, $p$ =.01), when covariates (gender, age, educational level, deprivation, and frequency of visits to natural environments) were included in the model. Stress was not significantly associated with BDS (β = -.08, 95 % CI = -.07, .02, $p$ =.32) when covariates were included in the model. Full tables of results are reported in the Supplementary Material.

### *3.6. Association between surrounding greenness, stress and memory performance*

A mediation analysis was run to explore the role of stress in mediating the relationship between surrounding greenness and memory performance. Surrounding greenness was used as the predictor, memory performance (FDS or TDS) as the outcome, stress as the mediator, and gender, age, educational level, deprivation and frequency of visits to natural environments as covariates (Fig. 3). Since neither surrounding greenness nor stress were significantly associated with BDS, as requested by steps 1 and 3 of Baron and Kenny's procedure (1986), the role of stress in mediating the relationship between surrounding greenness and this measure of memory performance was not investigated. Results showed that stress was a significant partial mediator of the relationship between surrounding greenness and FDS ($b$ = 1.04, SE = .70, 95 % CI = .04, 2.73). Stress was not a significant mediator of the relationship

**Table 2**
Correlations to identifying covariates.

| | Age[a] | Frequency of visits to natural environments[b] | Educational level[c] |
|---|---|---|---|
| FDS | rho = .08<br>$p$ = .26 | r = .32*<br>$p$ <.001 | F = 5.60*<br>$p$ = .001<br>f = 0.36 |
| BDS | rho = .10<br>$p$ = .17 | $r$ = .23*<br>$p$ <.01 | F = 12.22*<br>$p$ <.001<br>f = 0.48 |
| TDS | rho = -.09<br>$p$ = .26 | $r$ = .27*<br>$p$ <.01 | F = 11.77*<br>$p$ <.01<br>f = 0.46 |
| PSS | rho = -.26*<br>$p$ = .001 | $r$ = -.32*<br>$p$ <.01 | F = 2.02<br>$p$ = .11<br>f = 0.27 |

[a] Correlations between age and the outcome variables (FDS, BDS, TDS), and between age and the mediator (PSS) using Spearman's correlation (rho).
[b] Correlations between frequency of visits to natural environments and the outcome and mediator variables using Pearson's correlation (r).
[c] Difference between educational levels in the outcome and mediator variables using ANOVA (effect size for ANOVA is reported using Cohen's f).

between surrounding greenness and TDS ($b$ = 1.42, SE = 1.04, 95 % CI = -.06, 3.93) since the confidence intervals of the indirect effect included zero. Full tables of mediation analysis results are reported in the Supplementary Material.

## 4. Discussion

This study is the first to investigate the relationship between habitual exposure to surrounding greenness (as opposed to a short-term exposure, such as a walk in a natural environment) and memory performance in an adult population, using objective measures of both environment and memory. The study had two aims: to explore the relationship between surrounding greenness, memory, and stress, and to investigate the mediating role of stress in the relationship between surrounding greenness and memory. In relation to the first aim, surrounding greenness was associated with higher short-term memory, overall memory and lower levels of stress. In relation to the second study aim, stress mediated the relationship between surrounding greenness and short-term memory performance, independent of gender, age, educational level, deprivation and frequency of visits to natural environments.

The finding that surrounding greenness was associated with higher memory performance and lower levels of stress is in line with previous studies on the association between surrounding greenness and stress (Cox et al., 2017), and observed effects of a short-term exposure to natural environments on memory performance (Berman et al., 2012; Gidlow et al., 2016a). A systematic review on surrounding greenness and cognition (de Keijzer et al., 2016) included three studies in adult populations (Bodin et al., 2015; Kaplan, 2001; Tennessen and Cimprich, 1995) using subjective measures of either exposure to natural environments or cognition. The authors concluded that existing evidence of long-term exposure to surrounding greenness and cognition is inadequate but suggestive of a beneficial association.

Associations between exposure to surrounding greenness and cognitive functioning have been observed in other cross-sectional and longitudinal studies. One study found that each 100 m increase in distance to natural environments was associated with longer completion time of 1.50 % in a cognitive task (Zijlema et al., 2017). A longitudinal study on a sample of 6,506 participants found that one interquartile range increase in NDVI (using a 500-metre buffer around the home) was associated with a difference in the global cognition score of 0.02 over 10 years (de Keijzer et al., 2018). A retrospective study conducted on 281 participants found a significant association between lifetime availability of public parks in the 1500 m area surrounding the subjects' address and cognitive change from age 70 to 76 (Cherrie et al., 2018). Although the difference in the global cognition score and in the subscale scores of reasoning and fluency was small (de Keijzer et al., 2018), and the retrospective study found a modest effect size (Cherrie et al., 2018), these results are still relevant in terms of implications for cognitive functioning in the long term, considering the sample sizes used. These studies support our findings, showing that exposure to surrounding greenness is associated with better cognitive functions, and that surrounding greenness measured through the NDVI is an appropriate indicator of exposure to natural environments in the neighbourhood. Our study expanded the knowledge in this area by investigating what mediates this relationship.

This study showed the link between surrounding greenness (within 400 m of the home) and two distinct memory measures (short-term and overall). Previous systematic reviews on exposure to natural environments and cognitive functioning reported some uncertainty regarding which cognitive outcomes are most improved by exposure to natural environments. They have called for a consensus on the most appropriate measures to use (Ohly et al., 2016), further research on underlying pathways through mediation analysis (de Keijzer et al., 2016) and the use of exposure to actual natural environments rather than virtual (Stevenson et al., 2018), as this provides a stronger and more reliable effect. This study addressed these gaps by measuring three cognitive aspects and showing different effects of exposure to surrounding greenness on memory subtypes. However, it is worth commenting that the effect size found for the relationship between surrounding greenness

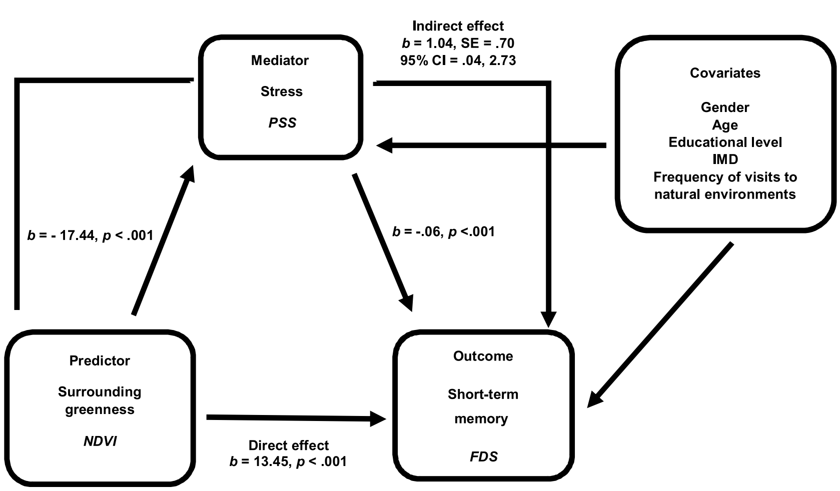


**Fig. 3.** Mediation analysis model tested. Surrounding greenness was used as predictor, short-term memory performance in the FDS task as outcome, stress as mediator, and gender, age, educational level, Index of Multiple Deprivation (IMD) and frequency of visits to natural environments as covariates.

and short-term memory ($r = .45$) and between surrounding greenness and overall memory ($r = .34$), can be considered very large and large, respectively (Funder and Ozer, 2019; Gignac and Szodorai, 2016). While an effect size of .30 can be powerful in the short and long run, an effect size higher than .40 could be an overestimate that might not replicate with a bigger sample. Therefore, results should be interpreted with caution and a larger sample size is recommended in future studies.

In this study, working memory, measured using the BDS, was not significantly associated with surrounding greenness and stress. In other studies, scores on the BDS task were significantly lower in people living in areas categorised as "barren" compared to those living in areas categorised as "green" (Kuo, 2001), but were not significantly different when comparing students having natural and built views from dormitory (Tennessen and Cimprich, 1995). School surrounding greenness and a total surrounding greenness index were also associated with a 12-month progress in working memory, measured using an n-back task similar to the BDS, in children aged 7–10 (Dadvand et al., 2015). This might indicate that, although there is support for the association of BDS and other tasks measuring working memory with exposure to natural environments (Ohly et al., 2016; Stevenson et al., 2018), this relationship might be less evident when looking at the effects of surrounding greenness.

Regarding the effects of stress on memory, three studies found no significant differences in BDS score and in a numerical n-back task score between participants assigned to a stressful condition and those in a control condition (Kuhlmann, 2005; Qin et al., 2009; Yuan et al., 2016), or between participants reporting low or high levels of stress (Yuan et al., 2016). However, others have found that administration of corticosteroids impaired working memory (McEwen and Morrison, 2013; Roozendaal et al., 2007; Young et al., 1999). This might suggest that the effects of stress on working memory are more evident when inducing stress physiologically rather than with stimuli or when measuring it with a questionnaire. In our study, the lack of association between working memory and surrounding greenness, and between working memory and stress, might be explained by the use of a chronic exposure to natural environments rather than acute, and a self-reported rather than a physiological measure of stress.

In the present study we found that stress mediated the relationship between surrounding greenness and short-term memory performance, independent of gender, age, educational level, deprivation and frequency of visits to natural environments. Links between stress and memory have been investigated previously. These results seemed to be explained by the model proposed by Sandi (2013), according to which intense chronic stress that is not related to a task mainly impairs explicit memory during the retrieval phase. Other studies found that cortisol impairs memory retrieval but enhances consolidation (Wingenfeld and Wolf, 2014), and that self-reported high levels of stress lead to an increase in the P2 amplitude, a component involved in the early stage of information processing (Yuan et al., 2016). Our results indicated that stress perceived by participants and that is not linked to the task might have impaired their short-term memory performance.

Exposure to natural environments benefits both stress and memory. Living in a neighbourhood with higher density of surrounding greenness has been associated with lower levels of hair cortisol (Gidlow et al., 2016b), and a short-term exposure to natural environments can confer a greater benefit to memory performance (compared to an urban environment) which persists 30 min after the exposure (Gidlow et al., 2016a). Also results of the present study support the hypothesis that stress is associated with exposure to natural environment and with short-term and overall memory, and stress can explain the relationship between the two.

These findings can be framed within both ART and SRT. Our results indicated that lower levels of stress were associated with higher exposure to surrounding greenness, as outlined by SRT, and exposure to areas with higher surrounding greenness was associated with a better cognitive performance, as explained by ART. Other studies showed a link between the effects of natural environments described by ART and SRT. Laumann et al. (2003) found that participants watching a video of natural environments had lower heart rate and showed no differences in reaction times to valid and invalid cues of an attention task, while participants watching a video of urban environments were faster on valid cues. Researchers proposed that reduced heart rate in participants watching a video of natural environments might have led to less spatially selective attention (improving performance in the task), suggesting a link between affective and cognitive effects of exposure to natural environments. Another study found that the improvement in completing the Necker Cube Pattern Control Task (an attention task), after watching and walking in natural environments, correlated with the improvement in self-reported positive affect (Hartig et al., 2003). However, others have found that improved working memory capacity and positive affect following a 50-minute walk in natural environments were not correlated, and it suggested that the cognitive benefits might be explained by processes beyond the simple increased positive affect (Berman et al., 2012).

In our study, mediation analysis suggested that effects explained by ART and SRT are linked. When stress and memory were included in the same model, stress was a significant mediator of the relationship between surrounding greenness and short-term memory, so that stress reduction described by SRT might explain the improved memory performance outlined by ART. One explanation is that stress is a general reaction of the body to a demand (Goldstein et al., 2002), and it involves several areas of functioning, including cognition, like the appraisal of the stressor (Lazarus and Folkman, 1984). Moreover, as first suggested by SRT, the initial response to natural environments is affective and it is later followed by a cognitive evaluation (Ulrich, 1983). This might then explain why stress mediates the relationship between exposure to natural environments and memory.

To summarise, the role of stress as a mediator was partial, as both direct and indirect effect were significant. This means that surrounding greenness predicted memory performance as measured by FDS (short-term memory), but its impact is mediated by stress. Conversely, stress was not a significant mediator of the relationship between surrounding greenness and TDS (overall memory) score. This might suggest that another factor mediates this relationship. For example, a review on long-term exposure to natural environments on cognition over the life course recommended the inclusion of social integration, depression, air pollution, noise and physical activity as mediators of the relationship between exposure to natural environments and cognitive functioning (de Keijzer et al., 2016). Studies that have used physical activity, social interaction with neighbours, loneliness, neighbourhood social cohesion, perceived mental health, traffic noise annoyance, worry about pollution, air pollution and social support as mediators of the relationship between natural environments and cognitive functioning did not find significant results (de Keijzer et al., 2018; Zijlema et al., 2017). Our study contributed to clarify the relationship between surrounding greenness and types of memory and its underlying pathways, but further research has been recommended (Ohly et al., 2016).

This study investigated the effects of exposure to surrounding greenness, i.e., exposure to natural environments in the neighbourhood, while controlling for the frequency of visits to natural environments. The purpose was to explore the benefits of exposure to natural environments beyond the intentional contact with them. This type of exposure included an indirect exposure (experiencing nature while not being physically in it, such as the view through a window or from the house) and incidental exposure (as a by-product of another activity, such as commuting to work), but it adjusted for intentional exposure (deliberate contact, such as recreational visits). These types of exposure have been previously described and researched (Garrett et al., 2019; Keniger et al., 2013). Surrounding greenness might also facilitate exposure to sounds of wind, flowing water, birdsongs and to the smell of fragrant plants, which were found to improve restorative capacity and subjective rating of calmness, alertness and mood (Weber and Heuberger, 2008; Zhao et al., 2018). Neighbourhoods with higher availability of surrounding greenness might also reduce exposure to air pollution and road traffic noise, which were found to be associated with poor mental health and prescription of anxiolytics (Klompmaker et al., 2019), although the effect of these factors was not explored here. Two studies showed benefits of surrounding greenness on cognition (Zijlema et al., 2017) and depression (Cox et al., 2017), when controlling for time spent outdoor. Therefore, there is evidence suggesting that different types of exposure to natural environments confer different effects, and that exposure to surrounding greenness alone can be enough to provide some benefits.

The strengths of this study were: to be the first study, to the best of our knowledge, to explore a mediator of the relationship between surrounding greenness and cognitive functioning, to objectively measure cognitive functioning through the use of tasks; to investigate memory performance using tasks measuring specific memory aspects (short-term, working and overall); to have contributed to the knowledge of the pathways underlying the relationship between exposure to surrounding greenness and cognitive functioning; to have suggested which cognitive aspects are most improved by surrounding greenness.

Some limitations are considered. First, the sample size was relatively small, although it was based on the effect sizes in similar studies (Kardan et al., 2015; Mears et al., 2019). A larger sample would have reduced the confidence intervals of the analyses and improved the accuracy of the estimates. However, statistical results were robust to controls for area deprivation. Second, the sample is not accurately representative of the population in the study area. Compared to data from a census and a report on population in Stoke-on-Trent, this sample was composed by more females (49.79 % in the census vs 58.4 % in this study), more educated people (24.3 % of people with a higher degree qualification indicated in the report vs 35.6 % in this study) and the percentage of people between 16 and 64 was 63.2 % in the report and 81.7 % in this study ("Population Estimates for UK, England and Wales, Scotland and Northern Ireland," 2019; Stoke-on-Trent and Staffordshire Area Review Final Report, 2016). In comparison to a recent study that included in the same areas, this study's sample was younger, more educated, composed by more females and living in areas with less surrounding greenness (Zijlema et al., 2017). Although recruitment was initially carried out via post to reach a heterogeneous audience in terms of socio-demographic characteristics, half of the sample was eventually recruited through flyers in the University premises. This might have resulted in a less representative sample, partly composed by students living in a similar neighbourhood (the University area), and therefore its characteristics should be taken into consideration when evaluating the findings. Third, the present study focused on exposure to surrounding greenness. Other types of exposure to natural environments have not been considered. These include natural environments in the work environment, exposure to images of natural environments or exposure to indoor nature such as plants. These types of exposure might have had an effect on memory performance of participants, but were not measured here. Fourth, other unmeasured variables might have affected memory performance and stress, such as mood, well-being, mental fatigue, and social relationships. Fifth, this was a cross-sectional study and, as such, it does not allow to infer a causal relationship between exposure and outcome, and neither a temporal one, since cross-sectional studies present data collected at one specific time point (Carlson and Morrison, 2009; Levin, 2006). However, this was considered the most appropriate design for our research questions as the aim was to explore an association between several variables (Carlson and Morrison, 2009; Mann, 2003), and a cross-sectional design was used previously when testing the mediating role of different factors in the relationship between surrounding greenness and other outcomes (Wang et al., 2019; Zijlema et al., 2017). Finally, other aspects of cognitive functioning like attention and perception have not been measured, and should be considered in future explorations of which cognitive aspects are most improved by exposure to natural environments.

## 5. Conclusion

Overall, our findings provide evidence for: associations between surrounding greenness and short-term memory, overall memory, and stress; associations between stress and short-term memory, and between stress and overall memory; and the mediating role of stress in the relationship between surrounding greenness and short-term memory. Stress mediated the relationship between surrounding greenness and short-term memory, while a mediator for overall memory was not found. To explore this pathway, future studies might consider other mediators, such as mood, well-being and social relationships. Moreover, parallel and serial mediation models could be used to test several mediators simultaneously or in sequence, and, other aspects of cognitive aspects should be investigated (e.g., attention and perception) to better define the role of surrounding greenness on cognitive functioning.


## Funding

This research was funded by Staffordshire University.


## CRediT authorship contribution statement

**Claudia Lega:** Conceptualization, Methodology, Formal analysis, Writing - original draft, Project administration. **Christopher Gidlow:** Conceptualization, Methodology, Writing - review & editing, Supervision. **Marc Jones:** Conceptualization, Methodology, Writing - review & editing, Supervision. **Naomi Ellis:** Conceptualization, Methodology, Supervision. **Gemma Hurst:** Conceptualization, Methodology, Supervision.

## Declaration of Competing Interest

The authors report no declarations of interest.


## Acknowledgements

The authors wish to thank Wayne Bamford for helping with the data collection and all study participants.


## Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:https://doi.org/10.1016/j.ufug.2020.126974.

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