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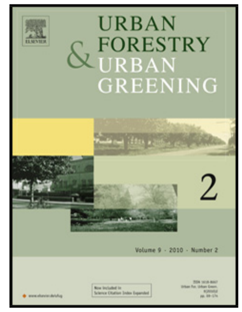

The relationship between surrounding greenness, stress and memory

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The relationship between surrounding greenness, stress and memory

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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 memory performance and lower levels of stress, and lower levels of stress were significantly associated with better memory performance. Stress was a significant partial mediator of the relationship between surrounding greenness and short-term memory, and between surrounding greenness and working memory. 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.

Keywords: natural environments; memory; stress; mediation

1. Introduction

There is evidence that exposure to natural environments is associated with positive health-related outcomes, such as better physical health (Browning & Lee, 2017), mental health (Van Den Berg et al., 2015), and self-reported general health (Orban, Sutcliffe, Dragano, Jöckel, & Moebus, 2017; Reid, Kubzansky, Li, Shmool, & Clougherty, 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 & 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, Hamilton, & Daily, 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 on 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, Maas, Verheij, & Grownewegen, 2010; Ward Thompson, Aspinall, Roe, Robertson, & Miller, 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), 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, Frantz, & Bruehlman-Senecal, 2009), and field studies (Johansson, Hartig, & Staats, 2011). The beneficial effect of natural exposure has been found for different processes of cognitive functioning such as attention (Berto, 2005), memory (Perkins, Searight, & Ratwik, 2011) and vigilance (Rich, 2008). Some studies exploring cognitive functioning have compared responses to natural and urban environments (Berman et al., 2012; Gidlow, Jones, et al., 2016; Laumann, Gärling, & Stormak, 2003). Others have explored cognitive functioning in different types of natural environments exposure, such as walking in a natural environment (Shin, Shin, Yeoun, & Kim, 2011), looking at natural environments through a window (Tennessen & Cimprich, 1995), and looking at pictures (Berman, Jonides, & Kaplan, 2008) or videos (Van den Berg, Koole, & van der Wulp, 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, Schilhab, & Bentsen, 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 of the relationship between natural environments and cognitive functioning (physical activity, social interaction with neighbours, loneliness, neighbourhood social cohesion, perceived mental health, traffic noise and worry about air pollution). 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 (Zijlema et al., 2017). 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, 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 residential 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, Formica, Dieterlen, & Morley, 2018). Stress has been measured through objective measures, such as cortisol as a marker of stress (Gidlow, Randall, Gillman, Smith, & Jones, 2016; Roe et al., 2013) and allostatic load (Egorov et al., 2017), and self-reported measures like questionnaires (Beil & Hanes, 2013). These studies support the link between exposure to natural environments and better stress outcomes. Stress is also associated with cognitive functioning, as it has been found to negatively affect memory performance in some studies (Kuhlmann, 2005; Schilling et al., 2013), but to facilitate implicit memory in another (Sandi, 2013), suggesting that relationship is complex and may depend on the type of memory.

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, van Dillen, Groenewegen, & Spreeuwenberg, 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, Pahl, White, & May, 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.

Overall, 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 ≥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 hectares (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 hectares of greenspace (including parks and gardens amenity green space and accessible natural greenspace) per 1,000 people (Green Space Strategy, 2018).

Participants were initially contacted via post, and later through e-mails and flyers in the University premises, using an opportunistic sampling method. 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 minutes, 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.

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.
- Occupational status. Single item question with six response categories: full-time work, part-time work, casual work, student/training, home duties, retired.

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.

Stress

- Perceived Stress Scale (PSS) – a self-report questionnaire developed by Cohen (1983) was used to evaluate perception of stress over the past four weeks. 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.

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, Ivnik, Price, & Wilkins, 2003) – The sum of the FDS and BDS scores gave an overall score that could range from 0 to 30. This score has been used previously as a measure of overall performance on digit span capacity and can be compared to normative data (Myerson, Emery, White, & Hale, 2003; Pisoni, Kronenberger, Roman, & Geers, 2011).

Exposure to natural environments

- Surrounding greenness was measured using the Normalized Difference Vegetation Index [NDVI, (Weier & 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 was calculated within a 400-metre buffer around the household, approximately equal to a five-minute walk.

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, Brindley, Jorgensen, Ersoy, & Maheswaran, 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. Gender was included as covariate a priori as literature supported its role on memory (Lynn & Irwing, 2008) and stress (Matud, 2004). Mediation analysis was undertaken in four steps following the procedure suggested by Baron & 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 characteristics

Complete data were obtained for 185 adults, with more women than men and a mean age of 42.21 [±18.79, range 18 to 91 (Table 1)]. Eighty-nine participants were recruited via post (49.4%), while 91 were recruited with e-mails and flyers (50.6%). Almost one third of the sample were employed full-time (29.8%) and 22.5% were students. 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%).

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).

Table1

Characteristics of study population (N = 185)

			FREQUENCY (%)	MEAN (SD)
	Gender	Male	77 (41.6)	
		Female	108 (58.4)	

Socio-demographic information	Age			42.21 (18.79)
	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)	
	Occupational status	Full-time work	53 (29.8)	
		Part-time work	34 (19.1)	
		Casual work	13 (7.3)	
		Student / training	40 (22.5)	
		Home duties	9 (5.1)	
		Retired	29 (16.3)	
Exposure to natural environments	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)
	BDS			6.87 (2.54)
	TDS			16.93 (4.88)
Stress	PSS			16.85 (8.30)

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

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 which was identified a priori.

Table 2

Correlations between outcome (FDS, BDS, TDS) and mediator (PSS) variables, and age, educational level and exposure to natural environments variables. Difference between occupational statuses in outcome and mediator scores.

	Age	Educational level	Occupational status	Frequency of visits to natural environments
FDS	rho = .08 *p* = .26	F = 5.60* *p* = .001	F = 5.47* *p* <.01	r = .32* *p* <.001
BDS	rho = .10 *p* = .17	F = 12.22* *p* <.001	F = 5.87* *p* <.01	*r* = .23* *p* <.01
TDS	rho = -.09 *p* = .26	F = 11.77* *p* <.01	F = 7.17* *p* <.01	*r* = .27* *p* <.01
PSS	rho = -.26* *p* = .001	F= 2.02 *p* =.11	F = 4.18* *p* = .01	*r* = -.32* *p* <.01

The following tests and statistics were used: Pearson's correlation (r), Spearman's correlation (rho), ANOVA (F).

3.3. Associations between surrounding greenness and memory performance

A linear regression, adjusted for gender, age, educational level, occupational status and frequency of visits to natural environments, showed that surrounding greenness was significantly and positively associated with FDS (b = 14.99, 95% CI = 10.40, 19.58, p < .001), BDS (b = 5.16, 95% CI = .97, 9.34, p = .02) and TDS (b = 20.15, 95% CI = 12.61, 27.68, p < .001). 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 (b = - 24.89, 95% CI = -10.20, -39.58, p = .001), when covariates (gender, age, educational level, occupational status 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 (*b* = - .10, 95% CI = -.15, -.044, $p < .001$) and TDS (*b* = -.14, 95% CI = -.22, -.05, $p < .001$), when covariates (gender, age, educational level, occupational status and frequency of visits to natural environments) were included in the model. Stress was not significantly associated with BDS (*b* = -.04, 95% CI = -.09, -.01, *p* = .08), 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, BDS or TDS) as the outcome, and stress as the mediator (Figure 1).

Results showed that stress was a significant partial mediator of the relationship between surrounding greenness and FDS (*b*= 1.59, SE = .90, 95% CI = .17, 3.62), and between surrounding greenness and TDS (*b*= 2.43, SE = 1.52, 95% CI = .14, 5.99). Stress was not a significant mediator of the relationship between surrounding greenness and BDS, since the confidence intervals of the indirect effect included zero (-.34, 2.75). Full tables of results are reported in the Supplementary Material.

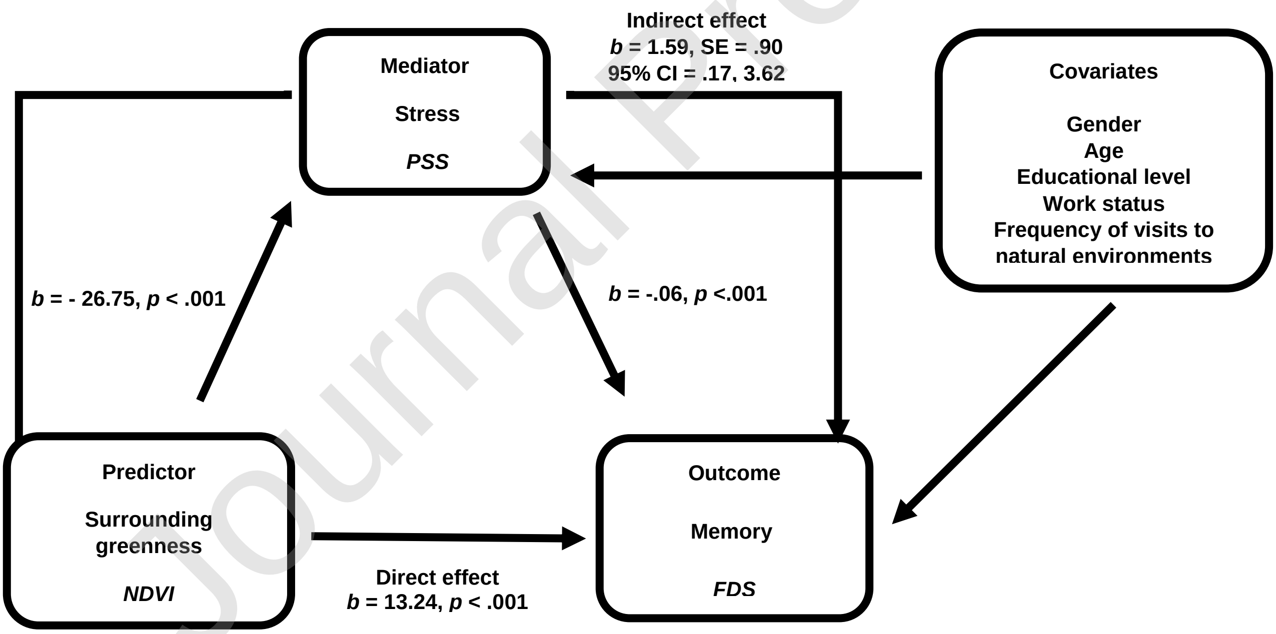

Figure 1. Mediation analysis model tested. Surrounding greenness was used as predictor, short-term memory performance in the FDS task as outcome, stress as mediator, and gender, age, educational level, occupational status and frequency of visits to natural environments as covariates.

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 memory performance and lower levels of stress. In relation to the second study aim, stress mediated the relationship between surrounding greenness and memory performance, independent of gender, age, educational level, occupational status and frequency of visits to natural environments.

The finding that surrounding greenness was associated with higher memory performance and lower levels of stress as 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, Jones, et al., 2016). A systematic review on surrounding greenness and cognition (De Keijzer et al., 2016) included three studies in adult populations (Bodin, Björk, Ardö, & Albin, 2015; Kaplan, 2001; Tennessen, 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 metres of the home) and three distinct memory measures (short-term, working, 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.

In the present study we found stress mediated the relationship between surrounding greenness and memory performance, independent of gender, age, educational level, occupational status and frequency of visits to natural environments. Links between stress and memory have been investigated previously. Memory retrieval was found to be significantly impaired after a stress-inducing condition, compared to a non-stressed control group (Kuhlmann, 2005). Another study showed that both task-related and task-unrelated stress can hinder explicit memory but might facilitate implicit learning (Sandi, 2013). Also cortisol, a glucocorticoid hormone released in response to stress, has been found to be associated with reduced memory performance in an inverted U-shaped manner, where participants with moderate salivary cortisol levels exhibited the best memory recall (Schilling et al., 2013). Overall, studies adopting different stress and memory measures suggest that stress affects memory performance negatively.

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, used as a measure of chronic stress (Gidlow, Randall, Gillman, Silk, & Jones, 2016), and a short-term exposure to natural environments can confer a greater benefit to memory performance (compared to an urban environment) which persists 30 minutes after the exposure (Gidlow, Jones, et al., 2016). Also results of the present study support the hypothesis that stress is associated with exposure to natural environment and with 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. Furthermore, 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, and between surrounding greenness and overall 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, McEwen, & Section, 2002), and it involves several areas of functioning, including cognition, like the appraisal of the stressor (Lazarus & 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 effects were significant. This means that surrounding greenness predicted memory performance as measured by FDS (short-term memory) and TDS (overall memory), but its impact is mediated by stress. Conversely, stress was not a significant mediator of the relationship between surrounding greenness and BDS (working memory) score. This might suggest that another factor mediates this relationship.

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. 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, social relationships, and socioeconomic status. 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.

Conclusion

Overall, our findings provide evidence for: associations between surrounding greenness and short-term memory, working memory, overall memory, and stress; associations between stress and short-term memory, and between stress and overall memory; the mediating role of stress in the relationship between surrounding greenness and short-term memory, and between surrounding greenness and overall memory. Stress mediated the relationship between surrounding greenness and two measures of memory (short-term memory and overall memory), while a mediator for a third measure of memory (working 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.

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Declaration of Interest
The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Supplementary Material

Results of regression analyses

Variables			Model Summary				Coefficients						
IV	DV	CV	R	R^2	Adjusted R^2	SE Est.	B	SE	β	*t*	Sig. (*p*)	CI Lower Bound	CI Upper Bound
NDVI	FDS	Gender Age Ed. Le. Oc. St. Fr. Vi.	.60	.36	.34	2.42	14.99	2.33	.46	6.44	<.001	10.40	19.58
NDVI	BDS		.51	.26	.23	2.20	5.16	2.12	.18	2.43	.02	.97	9.34
NDVI	TDS		.60	.36	.34	3.97	20.15	3.82	.37	5.28	<.001	12.61	27.68
NDVI	PSS		.45	.20	.17	7.58	-24.89	7.44	-.27	-3.35	.001	-39.58	-10.20
PSS	FDS		.51	.26	.24	2.58	-.10	.03	-.27	-3.67	<.001	-.15	-.044
PSS	BDS		.47	.23	.20	2.25	-.04	.02	-.13	-1.77	.04	-.09	-.01
PSS	TDS		.53	.29	.26	4.15	-.14	.04	-.23	-3.24	.001	-.22	-.05

Key:

IV = Independent Variable

DV = Dependent Variable

CV = Covariate

SE = Standard Error

Est. = Estimate

CI = Confidence Intervals

NDVI = Normalized Difference Vegetation Index in the 400-metre buffer around the household

FDS = Forward Digit Span task score

BDS = Backward Digit Span task score

TDS = Total Digit Span task score

PSS = Perceived Stress Scale score

Ed. Le. = Educational level

Oc. St. = Occupational status

Fr. Vi. = Frequency of visits to natural environments

Results of mediation analyses

IV	DV	CV	M								
NDVI	FDS	Gender, Age, Ed. Le., Oc. St., Fr. Vi.	PSS	**IV → M**							
				R	R^2	MSE	F	df1	df2	*p*	*b*
				.47	.22	55.52	7.61	6	162	<.001	-26.75
				M → DV							
				R	R^2	MSE	F	df1	df2	*p*	*b*
				.61	.38	5.69	13.85	7	161	<.001	-.06
				IV → DV (Direct effect)							
				b	SE	*t*	*p*	LLCI	ULCI		
				13.24	2.45	5.41	<.001	8.41	18.08		
				IV → M → DV (Indirect effect)							
				b	SE	LLCI	ULCI	Mediation			
				1.59	.90	.17	3.62	Partial			
NDVI	BDS	Gender, Age, Ed. Le., Oc. St., Fr. Vi.	PSS	**IV → M**							
				R	R^2	MSE	F	df1	df2	*p*	*b*
				.47	.22	55.52	7.61	6	162	<.001	-26.75
				M → DV							
				R	R^2	MSE	F	df1	df2	*p*	*b*
				.49	.24	4.84	7.26	7	161	<.001	-.03
				IV → DV (Direct effect)							
				b	SE	*t*	*p*	LLCI	ULCI		
				4.02	2.26	1.78	.08	-.43	8.48		
				IV → M → DV (Indirect effect)							
				b	SE	LL	UL	Mediation			
				.84	.79	-.34	2.75	Non sig.			
NDVI	TDS	Gender, Age, Ed. Le., Oc. St., Fr. Vi.	PSS	**IV → M**							
				R	R^2	MSE	F	df1	df2	*p*	*b*
				.47	.22	55.52	7.61	6	162	<.001	-26.75
				M → DV							
				R	R^2	MSE	F	df1	df2	*p*	*b*
				.60	.36	15.35	12.95	7	161	<.001	-.09
				IV → DV (Direct effect)							
				b	SE	*t*	*p*	LLCI	ULCI		
				17.26	4.02	4.29	<.001	9.31	25.20		
				IV → M → DV (Indirect effect)							
				b	SE	LLCI	ULCI	Mediation			
				2.43	1.52	.14	5.99	Partial			

Key:

IV = Independent Variable

DV = Dependent Variable

CV = Covariate

M = Mediator

MSE = Mean Square Error

df = Degrees of Freedom

SE = Standard Error

LLCI = Lower Level of Confidence Intervals

ULCI = Upper Level of Confidence Intervals

NDVI = Normalized Difference Vegetation Index in the 400-metre buffer around the household

FDS = Forward Digit Span task score

BDS = Backward Digit Span task score

TDS = Total Digit Span task score

PSS = Perceived Stress Scale score

Ed. Le. = Educational level

Oc. St. = Occupational status

Fr. Vi. = Frequency of visits to natural environments