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The relationship between natural outdoor environments and cognitive functioning and its mediators

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ABSTRACT

Background: Urban residents may experience cognitive fatigue and little opportunity for mental restoration due to a lack of access to nature. Natural outdoor environments (NOE) are thought to be beneficial for cognitive functioning, but underlying mechanisms are not clear.
Objectives: To investigate the long-term association between NOE and cognitive function, and its potential mediators.
Methods: This cross-sectional study was based on adult participants of the Positive Health Effects of the Natural Outdoor Environment in Typical Populations in Different Regions in Europe (PHENOTYPE) project. Data were collected in Barcelona, Spain; Doetinchem, the Netherlands; and Stoke-on-Trent, United Kingdom. We assessed residential distance to NOE, residential surrounding greenness, perceived amount of neighborhood NOE, and engagement with NOE. Cognitive function was assessed with the Color Trails Test (CTT). Mediation analysis was undertaken following Baron and Kenny.
Results: Each 100 m increase in residential distance to NOE was associated with a longer CTT completion time of 1.50% (95% CI 0.13, 2.89). No associations were found for other NOE indicators and cognitive function. Neighborhood social cohesion was (marginally) significantly associated with both residential distance to NOE and CTT completion time, but no evidence for mediation was found. Nor were there indications for mediation by physical activity, social interaction with neighbors, loneliness, mental health, air pollution worries, or noise annoyance.
Conclusions: Our findings provide some indication that proximity to nature may benefit cognitive function. We could not establish which mechanisms may explain this relationship.

1. Introduction

Natural outdoor environments (NOE) are places with natural ('green and blue') elements such as parks, forests, and recreation areas. Contact with natural outdoor environments has been suggested to be beneficial to human health and wellbeing (Hartig et al., 2014). However, a large proportion of the world's population currently lives in urban areas, where they are often deprived of contact with nature. One particular concern of city living is that residents may experience more stress than rural residents (Lederbogen et al., 2011; Gidlow et al.,

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2016a), making them more vulnerable to developing mental illnesses (Peen et al., 2010). Urban environments contain many stimuli that require directed attention due to, for example, traffic and crowding. Directed attention refers to the effortful, conscious attention for focusing on specific stimuli, while avoiding distractions. As a result, urban residents may experience more cognitive fatigue and little opportunity for mental restoration (Bratman et al., 2012).

The attention restoration theory (ART) proposes that directed attention, i.e. attention directed by cognitive control processes, is restored by interaction with nature. Natural environments are thought to have minimum requirements for directed attention, allowing for directed attention functions to restore (Kaplan and Kaplan, 1989). According to another theory, the stress reduction theory (SRT), nature helps to decrease stress by lowering states of arousal and negative thoughts. Natural places with certain characteristics (e.g. visible horizons for spotting of predators, availability of food) are from an evolutionary perspective better for survival, and may automatically evoke positive responses (Ulrich et al., 1991).

Evidence for a relation between NOE and improved cognitive function mainly originates from experimental studies typically focusing on short-term exposures (for a review, see Bratman et al. (2012)). Studies have observed improvements in memory capacity and attention after walking in natural environments, compared to walking in urban environments (Berman et al., 2008, 2012; Bratman et al., 2015; Gidlow et al., 2016b; Hartig et al., 2003). Other studies have evaluated visibility of NOE and relations with cognition; it has been found that people with a window facing a green space reported less concentration problems than those without a green view (Bodin et al., 2015), and that people were less likely to be forgetful and disorganized (Kaplan, 2001). Similarly, students with the most natural window view had better directed attention than those with built or concrete window views (Tennessen and Cimprich, 1995). Even viewing pictures of natural environments resulted in improved scores on attention tests (Berman et al., 2008; Berto, 2005). Other observational studies evaluating the beneficial effects of access to NOE on cognition have for example focused on working memory and behavioral development in children (Dadvand et al., 2015a; Amoly et al., 2014) and on cognitive function and dementia in older adults (Clarke et al., 2012; Wu et al., 2015). A recent review summarizing these studies reported that the number of available studies are limited and concluded that current evidence for such an association is inadequate (de Keijzer et al., 2016).

While most of the previous research focused on cognition benefits associated with NOE visibility, more indirect pathways may also be relevant to explore. Access to NOE may affect cognition indirectly by encouraging physical activity (Bancroft et al., 2015), facilitating social interaction (Maas et al., 2009), and by improving mood (Gascon et al., 2015), which may all be beneficial for cognitive function (Kuiper et al., 2016; Falck et al., 2016). Conversely, in environments with little nature, residents may be increasingly exposed to air pollution (Dadvand et al., 2015b) and traffic noise (Gidlöf-Gunnarsson and Öhrström, 2007). The exposure to air pollutants and noise and related worries and annoyance may influence cognitive functions (Tzivian et al., 2015; Clifford et al., 2016; Guxens et al., 2014; Sunyer et al., 2016).

There is, however, little evidence of the mechanisms underlying the relation between cognitive function and NOE. Evidence about the duration of these effects and its causality is also lacking. Another unresolved question is what type of interaction with NOE is needed for beneficial cognition effects. While most previous observational studies focused on residential distance to nature or surrounding greenness, the actual engagement with and perceived amount of nature in ones surroundings may also be important (Dadvand et al., 2016).

To gain further insight into the relation between long-term exposure to nature and cognitive function, we investigated the association between multiple NOE indicators and performance on the Color Trails Test (CTT), which assesses attention and executive function. We also evaluated the potential mediating roles of physical activity, social interaction, mental health, air pollution worries, and noise annoyance.

2. Methods

2.1. Study design and participants

The study was undertaken within the Positive Health Effects of the Natural Outdoor environment in Typical Populations in different regions in Europe (PHENOTYPE) project. This project was established to investigate the relationship between exposure to NOE and health and its underlying mechanisms in a sample of residents from four European cities: Barcelona (Spain); Doetinchem (the Netherlands); Kaunas (Lithuania); and Stoke-on-Trent (United Kingdom) (Nieuwenhuijsen et al., 2014). Participants were recruited from 30 neighborhoods per city that were selected in order to have variability in access to natural outdoor environments and socioeconomic status. From these neighborhoods, a random sample of 30–35 adults aged 18–75 were invited to participate, resulting in a sample of around 1000 participants per city (response rates were 46.9% in Barcelona; 8.4% in Doetinchem; 21.3% in Kaunas; and 36.9% in Stoke-on-Trent, see further details in van den Berg et al. (2016)). Data were collected alongside a face-to-face questionnaire administered at participants' residences during May-November 2013. In Kaunas (Lithuania), data were collected using a postal questionnaire and for this reason the CTT (our measure of cognitive function) could not be assessed in participants from Kaunas. Therefore, in the current study, only data from Barcelona, Doetinchem, and Stoke-on-Trent were used. All participants provided written informed consent and study protocols were approved by the local ethical committees.

A total of 1628 participants completed the CTT. From this sample, participants with incomplete data regarding indicators of the natural environment (n=83), mediators (n=222), and covariates (n=26) were excluded from the corresponding analyses, leaving between n=1493 and n=1602 participants for the current analyses depending on the exposure and mediator (see Tables 2–5).

2.2. Characterization of the natural outdoor environment

NOE were characterized with data using geographical information systems (GIS) and face-to-face questionnaires (Nieuwenhuijsen et al., 2014). Participants' residential addresses were collected and subsequently geocoded.

1. Residential distance to NOE was based on Urban Atlas 2006 (European Environment Agency, 2014) (Barcelona and Stoke-On-Trent) and Top10NL (Kadaster,) (Doetinchem) databases. Both databases use a 1:10,000 scale and a minimum represented unit of 0.25ha (Top10NL was adapted to be consistent with Urban Atlas). The Euclidean distance from residences to natural spaces > 1 ha (Annerstedt van den Bosch M et al., 2016) was calculated for the following land use categories: green urban areas (e.g. public gardens, parks) (14100), agricultural land, semi-natural areas, wetlands (20000), forests (30000), water bodies (50000) (European Environment Agency, 2006).
2. Residential surrounding greenness was assessed with the normalized difference vegetation index (NDVI). The NDVI is a measure of level of vegetation in a certain area and was derived from satellite images available from Landsat 8 at a resolution of 30 m×30 m. We aimed to find cloud-free images within the greenest season (May to September) in the relevant period for this study (2011–2013), and obtained images from 16th April 2013 (Barcelona area), 21st July 2013 (The Netherlands East), and 21st April 2011 (Stoke-on-Trent). The NDVI is based on the fact that healthy vegetation absorbs most visible light and reflects large parts of near-infrared light, while sparse vegetation reflects more visible light and less near-infrared