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Review

Environment as 'Brain Training': A review of geographical and physical environmental influences on cognitive ageing

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ABSTRACT

Global ageing demographics coupled with increased urbanisation pose major challenges to the provision of optimal living environments for older persons, particularly in relation to cognitive health. Although animal studies emphasize the benefits of enriched environments for cognition, and brain training interventions have shown that maintaining or improving cognitive vitality in older age is possible, our knowledge of the characteristics of our physical environment which are protective for cognitive ageing is lacking. The present review analyses different environmental characteristics (e.g. urban vs. rural settings, presence of green) in relation to cognitive performance in ageing. Studies of direct and indirect associations between physical environment and cognitive performance are reviewed in order to describe the evidence that our living contexts constitute a measurable factor in determining cognitive ageing.

Contents

1. Introduction

Increased life expectancy (Lutz et al., 2008) and the remarkable economic impact of caring for the older members of our society (Wimo et al., 2011; World Health Organization, 2012) make the support of independent living and ageing in place a global priority (Black, 2008; World Health Organization, 2012,2002). Cognitive health is a fundamental determinant of independent living and successful ageing (World Health Organization, 2002), and an urgent societal challenge considering the higher risk of cognitive decline and dementia with ageing (Prince et al., 2013; Sachs et al., 2011; World Health Organization, 2012).

The remarkable finding of brain plasticity (Diamond, 1988; Diamond et al., 1964; Gibson and Petersen, 1991; Greenwood and Parasuraman, 2010; Lövdén et al., 2010; Pascual-Leone et al., 2011,

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2005; Rosenzweig et al., 1962) supports the idea that our environment can contribute to shape brain structure and functions. Animals and humans exposed to richer environmental stimulation present fewer signs of brain degeneration (Hannan, 2014; Herring et al., 2009; Landau et al., 2012; Robertson, 2014,2013) and perform better in cognitive tasks than those not exposed to enriched environments (Berardi et al., 2007; Harati et al., 2011; Jankowsky et al., 2005; Robertson, 2013; Valenzuela and Sachdev, 2009). Animal studies in particular show that enriched environments can trigger morphological changes in the brain through sensory stimulation both in younger and older age (Baroncelli et al., 2012; Engineer et al., 2004; Landers et al., 2011; Nithianantharajah and Hannan, 2009). These studies are in line with the concept of cognitive reserve, which captures the idea that environmental stimulation can build resilience to cognitive ageing (Steffener et al., 2014; Stern, 2009,2002; Tucker and Stern, 2014). There are several forms of environmental stimulation: Individuals with higher levels of education, stimulating jobs and more advantaged socioeconomic backgrounds show lower risk of dementia in older age (Sharp and Gatz, 2011; Stern, 2012; Valenzuela and Sachdev, 2006); social engagement and exercise have been shown to benefit cognition in numerous studies (Colcombe and Kramer, 2003; Greenwood and Parasuraman, 2010; Hertzog et al., 2008; Kelly et al., 2014; Lövdén et al., 2005a; Ratey and Loehr, 2011); lastly, activities which offer mental stimulation influence hippocampal structural changes both in animals and humans (Erickson et al., 2011; Hertzog et al., 2008; Kelly et al., 2014; Kempermann, 2008; Kempermann et al., 1998,1997; Liu and He, 2012; Lövdén et al., 2012; Spalding et al., 2013; Valenzuela et al., 2008). These kinds of stimulation build cognitive and brain reserve allowing individuals who had ample opportunities for cognitive stimulation early in life to reach the threshold of cognitive pathology at an older age or at a more severe level of underlying brain damage than individuals whose life afforded fewer opportunities (Stern, 2012,2009,2002; Tucker and Stern, 2014). At the same time, targeted training interventions aimed to promote cognitive health in older age, defined as *brain training*, have proven effective in modifying the trajectory of cognitive ageing by improving performance in different areas of cognition, such as attention, executive functions and processing speed in a short or mid-term timeframe (Anguera et al., 2013; Ball et al., 2010; Edwards et al., 2005; Mozolic et al., 2011; Nouchi et al., 2012; Szelag and Skolimowska, 2012; Toril et al., 2014; Willis et al., 2006). Brain training is a thriving field of investigation in the area of successful ageing (Lustig et al., 2009) and has now reached a broad audience (Aamodt and Wang, 2007); however, further research is needed to understand whether trained cognitive abilities transfer to untrained skills and real life contexts (Green and Bavelier, 2008; Martin et al., 2011).

Despite the vast interest in cognitive reserve and brain training as preventative or remediating factors for cognitive decline (Green and Bavelier, 2008; Martin et al., 2011; Valenzuela and Sachdev, 2009), surprisingly little attention has been devoted to quantifying the cognitive benefits of the interaction of individuals with their geographical environment in everyday activities (Dunwoody, 2006; Wu et al., 2014), arguably the most pervasive and complex form of cognitive training or stimulation. For example, for an older person going to the shop, keeping in mind the route and the shopping list, while not being distracted by people and events occurring along the way, is a fundamental means of 'training' the brain, which is presumably performed several times a week. The difficulty of this environmental training depends on where the person lives, and possibly the time of the day and means of transport chosen to reach their destination – an issue explored for example in occupational therapy to maximise opportunities for independent living (Broome et al., 2009; Di Stefano and MacDonald, 2003). Similarly, while the effects of dual tasking in ageing have been extensively documented experimentally (Donoghue et al., 2013; Jain and Kar, 2014; Lindenberger et al., 2000), it is intuitive that crossing a busy road is a challenging form of multi-tasking, especially considering that older people may have slower walking speed, which makes the task difficult even in the absence of distractors (Romero-Ortuno et al., 2010).

In the present review, we argue that the geographical environment – defined in terms of rurality vs. urbanisation, presence of green, environmental layout and complexity, levels of traffic and noise – can act as a source of brain training and possibly contribute to cognitive resilience in older age, and that, in line with the Yerkes–Dodson law of optimal arousal (Yerkes and Dodson, 1908), environmental stimulation can either facilitate cognitive performance or cause cognitive overload depending on the relationship between levels of stimulation and the individuals' cognitive and physical functionality. Here we review studies which show an association between environmental characteristics and cognition, with a particular emphasis on physical or more broadly geographical aspects of the environment that influence perceptual and cognitive processing. As for any other form of brain training and cognitive stimulation, the challenge is to define the dimensions of the environment which contribute the most to support or hinder cognitive healthy ageing (World Health Organization, 2007), and to understand the association between these dimensions and specific cognitive skills. While acknowledging the important role of factors for cognitive health in older age such as education or occupation, which have been extensively explored in the literature (Albert et al., 1995; Hertzog et al., 2008; Stern, 2009), the present work explores measures that could be considered to operationalize the hypothesis of physical environment as a source of brain training/cognitive stimulation for future studies. We firstly discuss evidence of direct environmental influences on cognition drawing from epidemiological studies on urban/rural differences in the prevalence of cognitive impairment, from experimental studies on attention and distractibility in natural vs. urban environments, from the literature on spatial navigation and driving in relation to environmental layouts and visual clutter, and from studies on cognition and environmental noise. We then discuss mediating factors such as neighbourhood socioeconomic status (for example, neighbourhood affluence) and opportunities for active lifestyles (for example, exercise and walkability in the area of residence), which might moderate an indirect association between physical characteristics of the environment and cognitive health in older age. Fig. 1 summarizes the proposal that both direct (different exposure to, or interaction with, environmental stimuli) and indirect pathways (socioeconomic and lifestyle dimensions) link the environment with cognitive performance. By considering variables at different environmental levels going from broad geographical areas to characteristics of the proximal environment of residence, we aim to address environmental factors for cognitive health beyond simple macro urban/rural categories usually found in the literature. We focus on studies on older adults whenever they are available, otherwise considering studies on younger adults. New research questions and future developments to address this under-explored associations are discussed.

Understanding the influence of our lived environment on cognitive ageing will define strategies to modify or optimise environmental resources which improve cognitive ageing by supporting or even ameliorating specific cognitive abilities, in line with the evidence for environmental sustainability of health (Barton, 2009; Lavin et al., 2006). Importantly, it will also increase our capability to tailor brain training interventions to users' specific needs and environmental conditions, thus offering specific alternatives where urban planning is not an immediate option.

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