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Review

Gait in Parkinson's disease: A visuo-cognitive challenge

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ABSTRACT

Vision and cognition have both been related to gait impairment in Parkinson's disease (PD) through separate strands of research. The cumulative and interactive effect of both (which we term visuo-cognition) has not been previously investigated and little is known about the influence of cognition on vision with respect to gait. Understanding the role of vision, cognition and visuo-cognition in gait in PD is critical for data interpretation and to infer and test underlying mechanisms. The purpose of this comprehensive narrative review was to examine the interdependent and interactive role of cognition and vision in gait in PD and older adults. Evidence from a broad range of research disciplines was reviewed and summarised. A key finding was that attention appears to play a pivotal role in mediating gait, cognition and vision, and should be considered emphatically in future research in this field.

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1. Introduction

Parkinson's disease (PD) is a common neurodegenerative disorder characterised by cardinal motor symptoms such as rigidity, bradykinesia, tremor, postural instability and gait deficit (Jankovic, 2008). Gait impairments in PD include both continuous (constantly

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present) and episodic (freezing of gait (FOG)) (Nutt et al., 2011). Continuous gait impairment typically manifests as reduced velocity, step length, swing times, arm swing, increased gait variability and reduced automaticity. While episodic impairments emerge with increasing disease severity and are seen as hesitations when turning, a 'freezing' block in small spaces such as doorways and difficulty with gait initiation (Giladi et al., 2013). Gait impairments underpin difficulty walking in real-world environments such as maintaining a straight trajectory during gait (veering) (Davidsdottir et al., 2008), negotiating obstacles (Vitorio et al., 2013), and navigation (e.g. difficulties with narrow spaces such as doorways (Cowie et al., 2010) and misjudgement of object distance (Davidsdottir et al., 2005)). Moreover these problems are common and linked to falls (Paul et al., 2014). Although these problems emphasise the motor complications of PD, it is widely recognised that gait impairment is complex and reflects input from multiple systems that include both motor and non-motor systems (Grabli et al., 2012). For example, there is abundant evidence of the role of cognition in gait and increasing evidence of the role of vision. Understanding their respective contributions is critical in order to inform the mechanisms that drive gait impairment and to contribute to targeted therapeutic development to improve gait, independent mobility and falls risk.

A large body of evidence supports a robust relationship between cognition and gait, highlighting that gait is underpinned by cognitive functions (Lord et al., 2014). Cognitive impairments are common in PD with an estimated 40% of patients presenting with mild cognitive impairment (MCI) at diagnosis (Yarnall et al., 2014) and up to ~75% with dementia at ten years (Aarsland and Kurz, 2010). Previous studies have extensively investigated the relationship between gait and cognition (Amboni et al., 2013) using two methodological approaches. Associative protocols measure gait and cognition as separate behaviours and explore their relationship to identify links between them (Lord et al., 2014). Online protocols on the other hand, manipulate cognition particularly attention during walking through the use of dual-task protocols which show in real-time the contribution of cognition to gait (Kelly et al., 2012b). Such protocols demonstrate gait deficit such as reduced velocity and step length are associated with impaired cognition (Lord et al., 2014), and exacerbated using dual-tasks in PD (Kelly et al., 2012b).

Visual impairments are also common with up to 75% of people with PD experiencing at least one symptom such as blurred vision (Davidsdottir et al., 2005; Collerton et al., 2012; Urwyler et al., 2013). The relationship between vision and gait in PD has also been investigated either by exploring relationships between separate visual functions and gait or use of online protocols where vision is manipulated during gait (i.e. light or dark rooms) (Azulay et al., 1999; Almeida et al., 2005). Selective gait impairments are associated with deficits in visual functions (Moes and Lombardi, 2009), and exacerbated by visual manipulation in PD (Cowie et al., 2012). Studies have shown that visual functions contribute to gait control in PD (Azulay et al., 1999; Azulay et al., 2002; Khattab et al., 2012).

To date the relationship between gait, cognition and vision has received scant attention and is poorly understood. Cognition, vision and gait potentially interact in a selective but overlapping manner in order to plan routes and make ongoing modifications appropriate to changing environments. Static and more recently dynamic test protocols have been used to examine the interplay between cognition and vision. Static protocols range from simple associations between separate cognitive and visual outcomes, to more complex neuro-imaging or computerised saccadic (fast, jump-like) eye-movement assessment. Evidence from static tests supports an interaction between cognition and vision (Lee et al., 2015), and vice versa (Bertone et al., 2007; Toner et al., 2012). This interaction is encompassed by the term visuo-cognition, which is a global descriptor of interaction between cognitive and visual functions across multiple levels of information processing (Antal et al., 1998; Bandini et al., 2002). Visuo-cognition is therefore distinct from limited terms such as visuo-spatial function, which refers to the cognitive ability of the posterior parietal cortex to perceive the spatial relationship of objects (Benton and Tranel, 1993; Possin, 2010). Deficits in visual functions impact visuo-spatial ability due to their interaction (Stoerig and Cowey, 1997), but this exhibits only one aspect of visuo-cognition. Recent technological advances in mobile eye-tracking devices have facilitated measurement of saccadic eye movements during dynamic protocols (Land, 2006), which serve as a proxy measure of visuo-cognition during gait in PD (Stuart et al., 2014). To provide a detailed account of the role of vision and cognition during gait in PD there is first a need to understand the relationship and interactions between these two systems, and from these draw inferences about their potential impact on gait.

1.1. Study aims

A narrative review was undertaken to explore the diverse range of literature which was necessary to inform these complex interactive features. We adopt a model to explore the independent and interacting roles of vision and cognition in gait impairment in PD (Fig. 1) and highlight relevant literature pertaining to the role of cognition in gait (Fig. 1(A)); the role of vision in gait (Fig. 1(B)); the relationship between visual function and cognition (visuo-cognition) (Fig. 1(C)); and finally the role of visuo-cognition in gait (Fig. 1(D)). We explore evidence in PD and older adults, and make recommendations for future work in this complex and developing area.

2. The role of cognition in gait

Cognition is a multi-dimensional construct represented by interdependent systems, such as those described in Table 1. Attention is one of the most complex cognitive functions and is often considered to have overarching capacity (Lückmann et al., 2014) as a 'gatekeeper' or 'supervisory system' that allocates resources to competing processes (Posner and Petersen, 1990; Baddeley, 1992; Engle, 2002). Therefore if attentional deficit is present, other cognitive functions are also compromised (Posner and Petersen, 1990). For example, working memory is dependent on attentional processes to determine capacity and allocation (Kane et al., 2006).

Interpretation is complicated by the lack of a single and clear-cut definition of attention (Yogev-Seligmann et al., 2008). As a result, different theoretical and neuroanatomical models of attention exist which are in turn selectively applied to different areas of research (Posner and Petersen, 1990; Baddeley, 1992; Baluch and Itti, 2011; Petersen and Posner, 2012). However, most neuroanatomical models are consistent in describing attentional processes that originate from the pre-frontal cortex (PFC) which are associated with executive function (Aleman and van't Wout, 2008) and extend to include broader cortical networks including those with BG input (McNab and Klingberg, 2008). Attentional processes are also influenced by sub-cortical noradrenaline and cholinergic projections (Delaville et al., 2011; Müller and Bohnen, 2013), involving structures such as the locus coeruleus, thalamus, pedunculopontine nucleaus (PPN) and nucleus basalis of Meynert (Bohnen and Albin, 2011; Delaville et al., 2011; Gratwicke et al., 2015; Picillo et al., 2015). Dysfunction in any of these cortical or sub-cortical attentional networks with age or pathology may impact cognitive, visual or gait processes.

Visuo-spatial ability also shares a complex relationship with attention particularly in PD (Crucian and Okun, 2003; Crucian et al., 2010). Standard visuo-spatial assessments require attentional input from an early stage of visual processing to select focal areas