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# Preventing falls in older adults: Can improving cognitive capacity help?

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**Abstract:** Evidence linking physical health with beneficial cognitive outcomes is well established. However, the potential bi-directional nature of this relationship is far less explored. Falls-related injuries are frequently caused by age-related deterioration of walking gait, and cost the NHS in Britain ~£1 billion per annum. Interventions capable of reducing falls risk are significantly beneficial from both health and economical perspectives. In recent years, evidence has emerged suggesting that the cognitive capacity required for executive function and motor stabilisation share a fundamentally limited pool of neural resources. In tandem, research suggesting that computer-based cognitive training can—via neuro-plastic mechanisms—stimulate executive function enhancements. Subsequently, this suggests the possibility that cognitive training can positively impact motor control functions, such as walking gait. Thereby raising the potential that movement coordination may be enhanced through cognitive training interventions. This novel perspective is just beginning to be explored within the literature, and some intriguing evidence already exists. Accordingly, the objective of this discussion is to review the rationale and evidence underpinning the suggested linkage between cognitive resources and walking gait and to suggest how such interventions could provide novel, impactful and financially efficient practical applications for reducing the fall risk in older adults.

**Subjects: Motor Control and Development; Physical Activity and Health; Motor Skills; Cognitive Science; Cognitive Development**

**Keywords: cognitive training; cognitive capacity; walking gait; falls**

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## ABOUT THE AUTHOR

Joseph E. Robinson is a doctoral student at University of Central Lancashire, following completion of BSc (Hons) and MSc degrees on Sport and Exercise Science. He works for a family business promoting healthy and active lifestyles for the over 60s. He works on a day-to-day basis to develop the company and has created eLearning courses for CPD of exercise instructors. His interest in cognitive and physical function of older adults stemmed from his professional work. Hence, he is keen to ensure his research has a practical application to enhance the quality of life of this demographic. He aims to complete his PhD in 2017 and continue to research this area of science.

## PUBLIC INTEREST STATEMENT

Physical activity and exercise has been widely accepted as beneficial for both physical and cognitive function. Interestingly, recent research has shown that this link could potentially work reciprocally. Certain cognitive functions, called executive functions have been linked to physical actions such as one's walking gait. This suggests that interventions to improve cognition could also improve associated physical functions. Clearly, this holds significant potential to benefit quality of life for those whose cognitive and physical abilities are in decline, such as older adults. Furthermore, falls-related injuries cost the UK NHS in excess £1 billion per annum hence any intervention able to reduce the risk of falling holds significant economic benefit. This article will investigate this premise further and present evidence to discuss the potential of such interventions.

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## 1. Introduction

It is well known that in order to achieve and maintain physical health, one must partake in regular physical activity. With regard to promoting health and preventing disease in older adults (65 years and over) The American College of Sports Medicine (ACSM) and American Heart Association (AHA) recommends 30 min of moderate-intensity aerobic activity five times a week, or 20 min of vigorous-intensity aerobic activity three times a week, in addition to muscle-strengthening exercises at least twice a week (Nelson et al., 2007). In addition to this a meta-analysis of studies published between 1966 and 2001 revealed a significant positive effect of physical exercise on cognitive function in older adults (Colcombe & Kramer, 2003). Psychosocial benefits of physical exercise have also been reported in the literature (Taylor et al., 2004).

However, whether a bi-directional relationship exists is less clear as the potential consequences of cognitive training on physical function, such as walking, are far less prevalent within the literature. However, there is emerging evidence of a link between executive brain functions and walking gait, which holds potential for a novel approach to enhancing physical function through cognitive training. Accordingly, the aims of this article are to:

(1) Present current knowledge on physical and cognitive exercise and the functional interaction between them.

(2) Review emerging evidence surrounding cognition, cognitive training and walking gait, specifically in older adults.

(3) Suggest a logical conceptual framework explaining why cognitive training might improve walking gait.

## 2. Current knowledge: Physical exercise for physical and cognitive function

Adults over 50 years of age represent the most sedentary segment of the adult population, with 88% of over 65s living with at least one chronic health condition (King, Rejeski, & Buchner, 1998). Both low- (40–60% $VO_{2max}$) and high-intensity aerobic exercise (75% $VO_{2max}$) have been demonstrated to increase endurance capacity, by 12 and 20–30%, respectively (Lakatta, 1993). Further, studies have demonstrated that aerobic endurance training can lead to reduced body fat, fat mass and waist-to-hip ratios in 60–70-year-old men and women (Kohrt, Obert, & Holloszy, 1992). Moreover, resistance training in older adults has been shown to increase muscle strength and bone density, therefore, potentially reducing falls risk and the subsequent risk of fracture following a fall (Taylor et al., 2004).

As well as improving physical function, physical exercise has also been shown to positively affect cognitive function. This has been demonstrated in both children (Sibley & Etnier, 2003) and adults (Moonen, van Boxtel, de Groot, & Jolles, 2008), as well as across the human lifespan (6–90 years) (Etnier et al., 1997). In a recent study, cognitive function in older adults aged 50 years and over was reported to improve, after aerobic and resistance-based exercise programmes of at least moderate intensity (Northey, Cherbuin, Pumpa, Smee, & Rattray, 2017). Thus, illustrating the importance of physical exercise for the development and maintenance of cognitive function in childhood and adult life. Importantly for older adults, regular participation in physical exercise has been shown to attenuate cognitive decline (Fox, 1999), and has repeatedly been reported to reduce risk of cognitive impairment such as dementia (Barha, Galea, Nagamatsu, Erickson, & Liu-Ambrose, 2017). One potential reason is through aerobic exercise promoting the secretion of brain-derived neurotropic factor (BDNF), a protein that encourages the growth of new neurons termed *neurogenesis* and formation of new synapses termed *synaptogenesis*. Lower concentrations of BDNF are associated with Alzheimer's disease, Parkinson's disease, depression, anorexia and many other diseases (Adlard, Perreau, Pop, & Cotman, 2005). However, not all studies investigating the influence of BDNF on cognition have been positive. It is thought this may be due to the form of BDNF being tested, as the precursor molecule, pro-BDNF is neurotoxic, which is later converted into the neuroprotector, mature BDNF (Barha et al., 2017). Nonetheless, whether BDNF is the primary driver for morphological and structural changes to cognitive function in response to exercise or not, the benefits of physical exercise in the prevention of cognitive morbidities is clear (Taylor et al., 2004).

Strength, or resistance training (RT) seems to promote different responses to aerobic training, resulting in greater increases in levels of insulin-like growth factor 1 (IGF-1) (Kramer, Colcombe, McAuley, Scalf, & Erickson, 2005). Together, IGF-1 and BDNF interact to fulfil a neuro-protective function, preserving neuronal micro-architectures from progressive structural deterioration, thereby facilitating the preservation of higher order cognitive processes (Cassilhas et al., 2007; Kramer et al., 2005). Following aerobic training, such changes are less pronounced, thereby proposing different mechanisms through which aerobic and RT mediate cognitive enhancements (Barha et al., 2017). This, therefore, suggests the importance of both aerobic and resistance training to elucidate the cognitive enhancing effects of physical exercise, as previously reported (Northey et al., 2017). This is one potential explanation for the positive effects of physical exercise on cognitive function, as it stimulates biochemical and neurological processes, and thus influences change to cognitive capacity.

It is also evident that physical exercises promote psychosocial benefits such as reduced levels of depression (Kritz-Silverstein, Barrett-Connor, & Corbeau, 2001), enhanced mood (Arent, Landers, & Etnier, 2000) and reduced feelings of loneliness (McAuley et al., 2000). It is thought that the increased neurotropic factor expression and the increased opportunities for social interaction presented, for example, by attending an exercise class, are potential reasons for these psychosocial benefits (For further review see Duman, 2005; Taylor et al., 2004).

### *2.1. Current knowledge: Cognitive exercise for cognitive function*

Just as the body adapts in response to regular physical stimuli, the brain adapts to regular cognitive stimuli through robust neuroplasticity (Anguera et al., 2013; Fernandez & Goldberg, 2009). Such stimulation can be applied through adequately challenging, structured and focussed cognitive training (Fernandez & Goldberg, 2009; Gates & Valenzuela, 2010). As such, cognitive training demands that the participant attempts to solve novel cognitive challenges, specifically targeted to dimensions of cognitive function such as attention, working memory and processing speed. Thus, it requires the participant to stimulate specific functional brain networks on multiple occasions, promoting neurogenesis and synaptogenesis (Perrey, 2013).

Previous research has illustrated that cognitive training for older adults can drive the maintenance and enhancement of cognitive function (Anguera et al., 2013; Gates & Valenzuela, 2010). A systematic review by Keuider and colleagues (2012) examined 38 studies of computerised cognitive training methods with older adults between 1984 and 2011. The studies were split into three categories: classic cognitive training; to train specific aspects of cognition individually, neuropsychological software; designed to enhance multiple cognitive domains with a variety of tasks, and video games; involving manipulating “on-screen” images to achieve a goal (Kueider et al., 2012). All three types of training provided improvements to cognitive abilities with the authors concluding that computer-based interventions are less labour intensive than paper-and-pencil methods, and being technology savvy is not a requirement in order to benefit (Kueider et al., 2012).

These findings are of importance as cognitive decline is a common feature of ageing, particularly with regard to processing speed, working memory and inductive reasoning (Singer, Verhaeghen, Ghisletta, Lindenberger, & Baltes, 2003). Cognitive training of such functions has been shown to improve self-efficacy, and preserve independence in older adults (Wolinsky et al., 2009). Openness to experience—thinking creatively and enjoying intellectual pursuits—also declines with age, but can be increased following a period of cognitive training (Jackson, Hill, Payne, Roberts, & Stine-Morrow, 2012). Similar to physical exercise, it appears that participating in cognitive training has an indirect benefit of improving psychosocial health in older adults, as well as improving functional cognitive abilities.

## 3. Emerging evidence: Cognitive training for cognitive and physical function

Motor stabilisation is central to proficient movement execution (Skoyles, 2008). Uniquely within the animal kingdom, human’s predominant locomotive gait is bipedal in nature which poses unique stabilisation challenges requiring continuous skeletomuscular adjustments and multi-level neural control to maintain posture and on-going gait stability (Hausdorff, 2007; Skoyles, 2008). These adjustments require cognitive processing and demand uptake of neural resources, (Melzer, Benjuya, & Kaplanski, 2001) using sensory systems to anticipate destabilising perturbations and initiate remediating limb movements in advance of destabilisation occurring (Hausdorff, 2007; Skoyles, 2006). Therefore, it is clear that walking not only requires muscular activation, but also demands higher order neural processing capacity, dependant on the integration of input from cortical and sensory systems to coordinate locomotion (Hausdorff, 2007). As such cerebral cortical processing abilities and balance are closely linked (Skoyles, 2006) in which emerging evidence is beginning to explain and broaden the understanding of how it can be utilised to enhance cognitive and physical function.

### *3.1. Executive function*

Executive function refers to high-order cognitive processes that control, integrate and organise cognitive abilities to enable goal-orientated tasks such as decision-making and problem solving (Fernandez & Goldberg, 2009; Segev-Jacubovski et al., 2011). Recent evidence has suggested a close relationship exists between executive function and walking gait (Ijmker & Lamoth, 2012).

Walking is often thought of as an automatic task in young adults, requiring no cognitive effort (Smith-Ray et al., 2013), whereas in the early and late phases of life it is visibly less automated requiring greater conscious effort. The complex processing essential to anticipatory movement control to maintain a stable gait demands dedication of an inevitably limited reservoir of higher level cortical resources, not fully developed in the young, and in a state of decline in the old (Lacquaniti, Ivanenko, & Zago, 2012). Under normal walking conditions, gait pattern is relatively rhythmical due to the natural bilateral coordination of $\alpha$-motoneurons, controlled by spinal neuronal networks activating on both sides of the body in synchronisation (Ivanenko, Poppele, & Lacquaniti, 2006; Lacquaniti et al., 2012). When task constraints become unpredictable, and the consequence of error is high—for example, when traversing icy or broken surfaces—additional attentional capacity is required to effectively process sensorimotor information. The autonomous motor programme is, therefore, competing with high-level cortical capacity, or executive functions, to safely navigate the demanding environmental conditions. As individual safety is instinctively paramount, gait stability is prioritised to maintain an upright posture (Schabrun, van den Hoorn, Moorcroft, Greenland, & Hodges, 2014), and so the timing of muscle activation is altered to counteract perturbations and thus gait pattern becomes less rhythmical (Ivanenko et al., 2006; Skoyles, 2008).

Additionally, in persons with cognitive impairments such as, for example, Alzheimer's disease, deterioration of physical abilities such as walking decline in tandem with cognitive capacity (Wittwer, Webster and Menz, 2010). Many community-dwelling activities such as walking through a crowd of people depend on the successful execution of executive functions. Problem solving and decision-making ensure a safe route through the crowd, working memory ensures information can be manipulated in real-time, inhibition allows distractions to be withstood and mental flexibility allows the brain to quickly switch between functions (Fernandez & Goldberg, 2009; Smith-Ray et al., 2013). All this needs to take place along with the execution of motor function to allow the person to walk, regulate gait fluctuations (Decker, Cignetti, & Stergiou, 2013) and reduce the risk of falling through maintaining stability (Mirelman et al., 2012).

### *3.2. Linking executive function and physical function*

In the ageing brain, neural connections begin to deteriorate from 40 years of age (Fernandez & Goldberg, 2009). Authors have demonstrated an age-related decline in executive functions such as working memory (Buckner, 2004) and processing speed (Park, 2000). Multi-tasking performance also declines with age (Anguera et al., 2013), which requires executive functions such as mental flexibility and attention—a specific type of executive function (Segev-Jacubovski et al., 2011). Although age-related cognitive decline is an inevitability, its consequences can be offset through regular stimulation. Research has demonstrated that being cognitively active delays the onset of cognitive morbidities such as mild cognitive impairment, dementia and Alzheimer's disease (Wilson et al., 2010). It is thought the stimulation of different brain regions builds a resilience to decline likely to be due to its promotion of neurogenesis and synaptogenesis (Fernandez & Goldberg, 2009). Moreover, such declines in executive function have been demonstrated to present more than just reductions in cognitive function. For example, older adult fallers perform more poorly in computerised tests of executive function than their non-faller counterparts (Hausdorff et al., 2006). Similarly, older adult fallers with poor working memory overestimate their reach capacity by 16% compared to only 2% in older adult fallers with good working memory (Liu-Ambrose, Ahamed, Graf, Feldman, & Robinovitch, 2008). Further, in persons with dementia a reduction in walking gait velocity has been reported (Ijmker & Lamoth, 2012). Such findings support the aforementioned high-level cortical capacity demands of bipedal gait mastery and motor stabilisation. This capacity naturally declines with age, and is worsened with disease, but if stimulated regularly it can be maintained (Fernandez & Goldberg, 2009), benefiting both cognitive and physical function.

### 3.3. Dual-tasking

An implication of cognitive deterioration within the older adult population is increased falls risk. One key contributing factor to falls risk appears to be the decline of attention. This impacts on the ability to maintain focus on a stimulus to complete one or more tasks simultaneously (Segev-Jacubovski et al., 2011). This is known as dual-tasking which often occurs in community-dwelling daily living (Muir et al., 2012; Segev-Jacubovski et al., 2011). Should an individual be required to walk and complete a second attention-demanding task, the competition for resources within the cerebello-cerebral circuitry would lead to a deterioration of concurrent performance, posing a risk to safety by increasing the risk of falling (Schabrun et al., 2014; Skoyles, 2008). Furthermore, age-related deteriorations to the brain regions—primarily, but not exclusively, located in the prefrontal cortical areas—facilitating executive function, are reported to influence the risk of falling (Herman, Mirelman, Giladi, Schweiger, & Hausdorff, 2010).

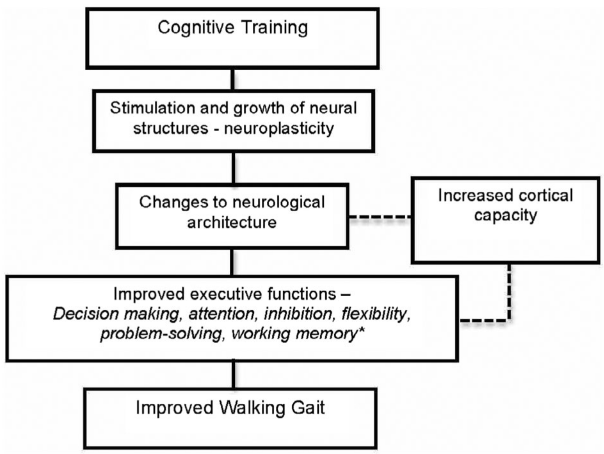
In a novel study, walking while reading and typing text on a mobile phone slowed walking gait, incurred postural changes and caused deviation from walking in a straight line (Schabrun et al., 2014). The cognitive task (reading or typing text) was prioritised over walking, as it is a more complex task, hence the walking gait was affected. The two tasks were unable to be executed simultaneously as they draw upon the same high-order cortical resources, forcing task prioritisation of the more cognitively complex task leading to a deterioration in performance (Segev-Jacubovski et al., 2011). The authors suggest that these changes to walking gait impact on the safety of the individual (Schabrun et al., 2014).

This affect has been further demonstrated in the literature by researchers who have asked participants to walk while performing cognitively stimulating tasks, such as counting backwards from 100 in ones or sevens (Muir et al., 2012). Inevitably this dual-task resulted in reduced gait velocity and increased stride time gait variability, indicating the gait pattern became unstable increasing the likelihood of a fall (Muir et al., 2012). In older adults with mild cognitive impairment or Alzheimer's disease, there is a much greater reduction to gait velocity than those with normal cognitive function (35% and 39% vs. 15%, respectively), and increases in stride time gait variability exceed the fall-risk threshold (Muir et al., 2012). Such findings highlight the increased risk of falling when cognition is in a state of decline, and completing more than one cognitively stimulating task simultaneously is required.

However, it is important to acknowledge that a deterioration of gait in the aged may be due to physical reasons such as arthritis, joint pain and diminished range of motion, leading to gait and balance disorders which influence gait variability and stride length (Salzman, 2010). The authors do not intend to suggest that changes to executive function will bring about transformations to structures such as joints and musculature. The intention here is to present the emerging evidence of a link between cognitive capacity—in particular executive function—and walking gait and how cognitive training may provide a novel solution to enhancing ones walking competence through potential hierarchical pathways (Figure 1).

**Figure 1. Hierarchical pathway to improve walking gait following a cognitive training programme.**

Source: *Fernandez and Goldberg (2009), Segev-Jacubovski et al. (2011).




## 4. Can executive function be improved?

Despite age-related cognitive decline often proving detrimental to health, studies have demonstrated that older adults can improve cognitive capacity, through specific training. A recent study by Saposnik and colleagues (2011) has shown how virtual reality gaming, which taxed decision-making and processing speed, enhanced motor function in stroke patients. It is thought that the games drive neurological change in the participants' brains, due to neuroplasticity, which leads to improvements in motor function (Saposnik et al., 2011). Essentially, the game works as a form of cognitive training stimulating neurogenesis and synaptogenesis as the brain "remodels" its neural network. In further support of this, playing a custom-designed video game improved the multi-tasking abilities of older adults (65–80 years old) to greater levels than those found in "untrained" 20-year-olds (Anguera et al., 2013). One hour per day, three times a week for one month playing the multi-tasking game enhanced cognitive abilities, which the authors claim is due to the robust plasticity of the ageing brain (Anguera et al., 2013).

Intriguingly, recent research suggests that dimensions of walking performance (specifically gait velocity and balance), can be improved in older adults, consequent to computerised cognitive training programmes (Smith-Ray et al., 2013; Verghese, Mahoney, Ambrose, Wang, & Holtzer, 2010). Ten weeks of computerised visual, spatial memory and decision-making games slowed the decline of walking speed and balance in a cohort of older adults on average 83 years of age (Smith-Ray et al., 2013). The authors attributed the results to the nature of the training, which focused on elements of executive function. Similarly, Verghese and colleagues (2010) reported a statistically significant improvement in walking speed ($0.68 \pm 0.20$ vs. $0.77 \pm 0.18$ $ms^{-1}$) in 10 sedentary older adults following an eight-week computerised cognitive training intervention. These findings hold even greater significance when considered alongside the increased likelihood of mortality at walking speeds less than 0.82 $ms^{-1}$ (Stanaway et al., 2011). Furthermore, the Advanced Cognitive Training for Independent and Vital Elderly (ACTIVE) study—the largest cognitive intervention study to date ($N = 2802$)—has demonstrated that training induced improvements to cognitive abilities such as memory, reasoning and processing speed are maintained for 24 months (Ball et al., 2002). Such findings demonstrate the robustness of the ageing brain and highlight the important role cognitive training can play in maintaining cognitive and physical function in the ageing population and it should be applied in a structured and specific manner.

## 5. Conclusions

Studies have outlined the importance of physical exercise for physical, cognitive and psychosocial function (Colcombe and Kramer, 2003; Duman, 2005; Nelson et al., 2007). Similarly, cognitive training has also been shown to be beneficial to cognitive and psychosocial health (Anguera et al., 2013; Gates & Valenzuela, 2010). These outcomes are advantageous in terms of attenuating age-related declines to biopsychosocial well-being. However, approximately 50% of community-dwelling older adults aged 85 and over will fall each year. Crucially, those with a cognitive impairment are twice as likely to suffer a fall (Iinattiniemi, Jokelainen, & Luukinen, 2009). This not only impacts individuals, but also has huge economical implications with fall-related treatment costing the UK NHS ~£1 billion per annum (Davis et al., 2010).

The uniqueness of human bipedal gait demands high-level cognitive processing to enable motor stabilisation and an erect posture suggesting that cognition and gait mastery share cerebello-cerebral circuitry (Skoyles, 2008). Recent evidence has emerged within the literature suggesting such a link between executive function and walking gait (Ijmker & Lamoth, 2012) and its impact on fall risk. It has, therefore, been suggested that improving executive function would reduce falls risk (Segev-Jacubovski et al., 2011).

One method of doing this is via computerised cognitive training and measuring the impact on characteristics of walking gait, such as stride length, stride time and stride time variability in single and dual-task environments. Studies such as Verghese and colleagues (2010) and Smith-Ray and colleagues (2013), have shown the power of cognitive training to reduce the effects of cognitive decline and how this impacts on walking gait velocity and balance. The neuroplasticity and robustness of the ageing brain to rejuvenate has also been demonstrated (Anguera et al., 2013; Bherer et al., 2005, 2008; Saposnik et al., 2011). Importantly, however, further research is needed to broaden understanding of the relationship between this type of cognitive function and walking gait. Furthermore, the utility of computerised training to augment cognitive capacity may, following the rationale and evidence presented here, prove a novel intervention capable of indirectly reducing falls risk in the ageing population.

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The authors declare no competing interest.

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