



Review Article

Impact of cognitive fatigue on gait and sway among older adults: A literature review

Stephanie Grobe ^a, Rumit Singh Kakar ^b, Matthew Lee Smith ^{c,d}, Ranjana Mehta ^e,
Timothy Baghurst ^f, Ali Boolani ^{a,*}

^a Clarkson University, Dept. of Physical Therapy, Potsdam, NY 13699, USA

^b Ithaca College, Dept. of Physical Therapy, 953 Danby Rd., Ithaca, NY 14850, USA

^c University of Georgia, Institute of Gerontology, Dept. of Health Promotion and Behavior, Health Sciences Campus, #101 Hudson Hall, Athens, GA 30602, USA

^d Texas A&M University, School of Public Health, Dept. Health Promotion and Community Health Sciences, 212 Adriance Lab Rd, 1266 TAMU, College Station, TX 77843-1266, USA

^e Texas A&M University, Dept. of Environmental and Occupational Health, 212 Adriance Lab Rd, 1266 TAMU, College Station, TX 77843-1266, USA

^f Oklahoma State University College of Education, 189 Colvin Center, Stillwater, OK 74078, USA

ARTICLE INFO

Article history:

Received 22 November 2016

Received in revised form 14 February 2017

Accepted 18 February 2017

Available online 24 February 2017

Keywords:

Older adults

Elderly

Cognitive fatigue

Mental fatigue

Falls

Fall risk

Gait

Sway

ABSTRACT

The Abstract

The Abstract is a summary of the paper. It is often a collection of mini-summaries: a one sentence summary each of the intro, the methods, the main findings. You'll note that in this case the abstract maps onto the Headings used in the contents. Follow the highlighting.

Cognitive fatigue is an alteration in central nervous system (CNS) processing due to prolonged performance of mentally demanding tasks. Decreased **gait** speed and increased stride length variability have been noted in cognitively fatigued older adults (≥ 65 years). Further, cognitive fatigue may weaken the visual, vestibular, and proprioceptive systems of the CNS, contributing to increased postural **sway**. **Detriments in gait and sway caused by** cognitive fatigue could increase **fall risk**. The objective of this literature review was to evaluate the impact of cognitive fatigue on changes in gait and postural sway and its role in fall risk.

The Objective at the end of the intro is not the preferred location. Often the conclusion goes there.

Contents

1. Methodology	89
2. Cognitive fatigue	89
3. Gait	89
4. Postural stability and sway	89
5. Impact of cognitive fatigue on gait	90
6. Impact of cognitive fatigue on sway	90
7. Fall risk implications.	90
8. Conclusion	91
Acknowledgments	91
Appendix A	91
References.	92

Introduction

By the year 2030, over 20% of the population will be over the age of 65 (Center for Disease Control and Prevention, 2015). Older adults (i.e.

individuals aged 65 years and older) are more prone to falls. In 2013, direct fall-related costs were estimated to exceed \$34 billion, and falls incidence rates and associated financial costs continue to rise (Center for Disease Control and Prevention, 2015). Falls among older adults have been known to cause institutionalization, premature mortality, and increased use of healthcare services (Rubenstein, 2006). Approximately two-thirds of unintentional injury deaths within the older adult population are attributed to falls, and over 45% of those aged 75 years and older experience a fall each year (Cebolla et al., 2015). The prevalence of falls among the older adult population may be related to diminished neuromuscular functioning, which accompanies natural aging. Examples include reductions in balance, muscle strength, peripheral sensation, vision, and cognition, which have all been associated with increased fall risk among older adults (Martin et al., 2013).

Common cognitive disorders among the older adult population including stroke, Parkinson's disease, and dementia (including mild cognitive impairment) have been reported to increase fall risk (Fischer et al., 2014). More recently, declines in the cognitive abilities of healthy older adults have been associated with increased fall risk (Herman et al., 2010). The most common reason for mildly impaired cognitive function among older adults is cognitive fatigue, a failure to sustain attention for optimal performance (Holtzer et al., 2011). Consequently, cognitive fatigue may cause changes in gait and postural sway among older adults because both tasks require higher order neurological processes (Herman et al., 2010). To the authors knowledge there is no current literature that examines the role of cognitive fatigue in falls and fall risks. Therefore, the objective of this literature review was to examine the current literature to assess the role that cognitive fatigue may have on gait and postural sway. A better understanding of cognitive fatigue's role in gait and postural sway may raise awareness among researchers and healthcare professionals about this important risk factor and guide future efforts to integrate this knowledge into fall prevention protocols and future studies to examine the role of cognitive fatigue in fall risk factors.

This intro follows the usual format of moving from general to specific. This is the same kind of intro you write in an argument essay. It is not a literature review. The actual topic of this paper is "fall risk due to cognitive fatigue," which you'll note isn't specifically stated till the middle of the last paragraph.

The intro often starts with a connection to the real world that establishes importance for a general reader.

The 3rd sentence focuses on from age to fall risk.

This paragraph establishes the importance of falls.

This mention of 'cognition' in a list of other possible causes is a clever way to subtly guide the reader to a further narrowing of the topic in the following paragraph.

The first part of this paragraph gives background on cognitive disorders. Only after the reader is oriented to cognitive disorders and decline is the real topic of 'cognitive fatigue' introduced.

At this point, at the end of the intro is where the authors establish the gap in the intro. Establishing the gap is crucial and is a standard component of academic and professional writing. The authors have pointed out all the relevant areas of studies which would logically seem to converge on this combined topic of cognitive fatigue and falls. The fact that there isn't anything published on precisely this topic means it is ripe for investigation.

The authors end with the purpose of this paper which is to have an impact on understanding and on protocols etc.

1. Methodology

A literature search was conducted from July 1, 2015 to July 5, 2015 using Medline, Science Direct, Pubmed, CINAHL, and Cochrane library databases for articles published between June 2005 and June 2015. The following combination of mesh terms were used “fall risks” or “falls” and “cognitive fatigue” or “central fatigue”.

We were unable to find literature that directly linked central or cognitive fatigue to falls, therefore we changed our search strategy to reflect a literature review to indirectly link central or cognitive fatigue to falls and fall risks. To conduct the literature review we used the following mesh terms “fall risk older adult” or “fall risk elderly”; “central fatigue elderly” or “mental fatigue elderly” or “cognitive fatigue elderly”; “fatigue and gait elderly” or “fatigue and gait older adults”; “fatigue and sway elderly” “fatigue and sway older adults”.

Note that the authors had to chance their method. It's not always important to do that, especially if you start out with trial and error searching. In this case however, the lack of information that was directly related to the topic may indicate the worthwhileness of the topic.

Note the relationship between search terms and the key words listed for the article on the first page.

You might consider other points to include in a methods section of this type such as how many results, how results were refined, how articles were valued or whether the data was transferable.

Sections 2-5 are similar background sections. So only one section is included here.

Notice the headings format.

In this journal, the style is to use a number and upper case only for the first word.

In your own paper, use the headings formatting in Word as that will create your table of contents automatically.

This background paragraph is set up in the classic analytical style. It starts with a general definition in the classic formula: X is a type of Y. Then extends the definition by

- classifying types
- explaining cause/effect and/or reason/result
- comparing to like terms and differentiating from terms that might be confusingly similar

2. Cognitive fatigue

Fatigue is a temporary loss of strength and energy resulting from hard physical or mental work (Gardiner et al., 2009). The word “fatigue” can refer to peripheral fatigue or central fatigue (Holtzer et al., 2011). Cognitive fatigue, a component of central fatigue (Holtzer et al., 2011), is a psychobiological state caused by prolonged periods of demanding cognitive activities (Marcora et al., 2009). It is characterized by feelings of tiredness and lack of energy (Marcora et al., 2009), and results in failure to maintain attention necessary for optimal performance (Holtzer et al., 2011; Shortz et al., 2015). Acute cognitive fatigue is a common part of everyday activities, such as driving through traffic (Marcora et al., 2009), but can also arise from sustained performance of multiple tasks requiring mental effort, such as fatigue after a work day in the office (van der Linden et al., 2003). Fatigue is usually accompanied by weariness and reduced alertness, which could contribute to decreased productivity and accidents (Liu et al., 2010).

Prolonged performance of a mentally-demanding task causes changes in the activation of the prefrontal cortex (Tanaka et al., 2014), an area of the brain involved with executive function. Tanaka et al. (2014) found that performing a mental fatigue-inducing task causes increased beta-frequency band power, which may be related to decreased brain alertness and arousal levels (Tanaka et al., 2014).

Individuals experiencing cognitive fatigue have reported difficulty when performing tasks that require attention and concentration (Boksem et al., 2006). Decreased efficiency of attentional allocation causes a decline in efficiency when performing a task during or following a mentally-fatigued state (Boksem et al., 2006). Another reason for decreased performance when cognitively fatigued may be impaired action monitoring (i.e. the ability to use environmental information to adjust ongoing behavior) (Boksem et al., 2005). Cognitive fatigue among older adults may lead to changes in gait and postural control, both of which require cognitive processes (Herman et al., 2010).

Notice the citations: Each sentence is cited as needed. Since this is a background paragraph, there is not a much variety among sources.

- Don't be afraid to use a lot of citations.
- Don't confuse citations with quotations. Quotations are to be used sparingly, but citations are to be used A LOT.

Notice that this last sentence functions as a hypothesis which will also lead into the next section defining “Gait.”

Sections 5-7 are similar as this is where the literature is being reviewed. Note the mention of the tables and the synthesis of the sources.

5. Impact of cognitive fatigue on gait

Walking while performing a secondary task, or DT, that demands attention has been used to assess the relationship between cognition and gait. Four studies presented in Table A.1 measured gait parameters among samples of older adults walking while performing a simultaneous cognitive task (DT condition), and compared the results to the gait parameters measured while walking alone (single task condition). The findings of Hall et al. (2011) (Hall et al., n.d.) and LaRoche et al. (2014) (LaRoche et al., 2014) may suggest changes in gait parameters observed during DT walking are a consequence of reduced cognitive function associated with aging. Hall et al. (2011) (Hall et al., n.d.) found that cognitive factors contributed to participants' ability to walk and perform a complex cognitive task (Hall et al., n.d.), and participants walked slower under the DT condition than the single task condition regardless of the cognitive task being performed (Hall et al., n.d.).

LaRoche et al. (2014) found changes in gait parameters under DT conditions for participants in their 70s, but not for participants in their 50s and 60s. In general, gait variability across conditions was greatest for subjects in their 70s (LaRoche et al., 2014). These results may support the hypothesis that cognitive fatigue increases gait variability among older adults. Competition for attentional resources is observed under DT because the brain is forced to unconsciously decide which task to prioritize (Beauchet et al., 2005).

Walking while cognitively fatigued may be viewed as a DT condition because the attention required for stable gait is diminished as a result of fatigue. Cognitive fatigue may be analogous to the secondary cognitive tasks used in previous DT studies; both cognitive fatigue and the secondary cognitive task diminish the attentional resources that are needed for stable gait.

Verlindin et al. (2014) performed cognitive and gait assessments with 1232 participants from the Rotterdam Study (population based study in the Netherlands to explore causes and determinants of chronic diseases among middle-aged and older adults). Cognitive assessments consisted of tasks testing memory, information processing speed, fine motor speed, and executive function. Seven independent domains were used to assess gait, namely rhythm, variability, phases, pace, tandem, turning, and base of support. Information processing speed was associated with rhythm, which reflects temporal gait parameters including cadence, stance time, and swing time. Fine motor speed was associated with tandem, which reflects amount of errors during tandem walk including side steps and double steps. Executive function was associated with pace, which reflects distance related variables including stride length and gait velocity (Verlindin et al., 2014). These findings show that cognition and gait have a distinct pattern of association (Verlindin et al., 2014). Therefore temporary cognitive impairments due to fatigue may cause gait changes that could be detrimental to older adults.

8. Conclusion

Current literature discusses the impact of reduced cognitive functioning on gait and postural sway among healthy older adults. Cognitive fatigue temporarily impairs cognitive functioning, and therefore, cognitive fatigue may impact gait and postural sway during the fatigued physiological state. Cognitive fatigue may increase gait variability and increase postural sway in the same way as reduced cognitive functioning.

This literature review found that cognitive fatigue may be considered a fall risk for older adults, irrespective of their health status. Clinicians and caretakers are encouraged to practice caution when aiding a cognitively fatigued older adult during ambulation. Caretakers should especially attend to older adults that are considered a fall risk in the absence of fatigue, because fall occurrence is likely to be exacerbated when mentally tired.

Future studies should be performed to evaluate the impact of cognitive fatigue on gait and sway among healthy older adults. For example, a potential study could induce cognitive fatigue among healthy older adults using a mentally-demanding task. Gait and postural sway could be measured before and after cognitive fatigue induction to evaluate the impact of cognitive fatigue on each parameter. Multiple studies with such measurements would reveal whether or not cognitive fatigue may be considered a fall risk for older adults.

If cognitive fatigue is identified as a fall risk, various interventions could be developed to attenuate cognitive fatigue. Further strategies to reduce cognitive fatigue could be integrated into existing evidence-based fall prevention programs for older adults, which are already known to improve gait and balance (e.g. A Matter of Balance, Tai Chi, Stepping On) (Cho and Smith, 2015; Ory et al., 2015a; Ory et al., 2015b). Efforts to understand the role of cognitive fatigue could be incorporated in the Otago Education Program, a physical-therapist driven fall prevention intervention for frail older adults (Shubert et al., 2015). Such an effort could enable the impact of cognitive fatigue as a fall risk to be explored under the close supervision of a trained professional, mitigating possible injury.

Acknowledgments

The authors would like to thank Clarkson University's Community of Underrepresented Professional Opportunities (CUPO), as well as Gabriela Arita, Holly Bronson, and Brianna Weber for their support on this paper.

This first paragraph is a summary of the findings. This one is quite general; others can be quite specific with % of articles, etc.

This paragraph is moving into the implications of the findings. Note that there is hedging in wording choices like "may be" and "likely."

Recommendations for Future Studies

Recommendations for Interventions

Appendix A

Table A.1

Impact of cognitive fatigue on gait.

Study	Study population	What was measured	Main findings
Dubost et al. (2006)	45 healthy older adults (65.3 ± 3.2)	Gait parameters during walking at normal and slow self-selected speeds under single and DT conditions	Under DT: decrease in mean values of stride velocity and increase in mean values and coefficients of stride time variation
Hall et al. (2011)	77 older adults (75.5 ± 5.8)	Strength, gait speed, static and dynamic balance, cognitive abilities (psychomotor and perceptual speed, recall and working memory, verbal and spatial ability, attention); time to walk while performing 4 cognitive tasks, DT costs calculated	Walking and performing a simple cognitive task explained by participant characteristics and motor factors alone; walking and performing a complex cognitive task explained additionally by cognitive factors;
Hashimoto et al. (2014)	201 elderly without dementia (67.8 ± 6.5)	Brain MRI, neuropsychological tests, gait parameters, TUG: time and number of steps under single and DT conditions	Impaired gait velocity of TUG associated with deep white matter lesions and diabetes mellitus after adjusted for age, sex, education, and cognitive function tests; impaired gait velocity of DT associated with age and score of Rivermead Behavioral Memory Test
LaRoche et al. (2014)	42 healthy men and women (50–80, separated by decade)	Cognitive function assessed with Mini-Mental State Exam (MMSE) and Trail Making Test (TMT); DT walking at self-selected speed under 3 cognitive loading conditions	Time to complete TMT positively correlated with age, stride time, and double-limb support time; subjects in 70s increased double-limb support time and stride time during most difficult DT condition
Verlindin et al. (2014)	1232 subjects from the Rotterdam Study (66.3 ± 11.8)	Cognitive and gait (7 independent domains: rhythm, variability, phases, pace, tandem, turning, base of support) assessments	Information processing speed associated with rhythm; fine motor speed with tandem; EF with pace

Notice the Label for Tables is above the table, while for Figures, the label goes below.

References

- Amboni, M., Barone, P., et al., 2013. Cognitive contributors to gait and falls: evidence and implications. *Mov. Disord.* 28:1520–1533. <http://dx.doi.org/10.1002/mds.25674>.
- Barak, Y., Wagenaar, R.C., et al., 2006. Gait characteristics of elderly people with a history of falls: a dynamic approach. *J. Am. Phys. Ther. Assoc.* 86:1501–1510. <http://dx.doi.org/10.1007/s11357-014-9693-5>.
- Beauchet, O., Dubost, V., Herrman, F., Kressig, R., 2005. Stride-to-stride variability while backward walking among healthy young adults. *J. Neuroeng. Rehab.* 2 (26). <http://dx.doi.org/10.1186/1743-0003-2-26>.
- Bergamin, M., Gobbo, S., et al., 2014. Influence of age on postural sway during different dual-task conditions. *Front. Aging Neurosci.* 271 (6). <http://dx.doi.org/10.3389/fnagi.2014.00271>.
- Bisson, E.J., et al., 2011. Effects of ankle and hip muscle fatigue on postural sway and attentional demands during unipedal stance. *Gait Posture* 33:83–87. <http://dx.doi.org/10.1016/j.gaitpost.2010.10.001>.
- Boksem, M., Meigman, T., Lorist, M., 2006. Mental fatigue motivation and action monitoring. *Biol. Psychol.* 72:123–132. <http://dx.doi.org/10.1016/j.biopsycho.2005.08.007>.
- Boksem, M., Meijman, T., Lorist, M., 2005. Effects of mental fatigue on attention: an ERP study. *J. Cogn. Brain Res.* 25:107–116. <http://dx.doi.org/10.1016/j.cogbrainres.2005.04.011>.
- Bryant, E.C., Trew, M.E., et al., 2005. Gender differences in balance performance at the time of retirement. *Clin. Biomech.* 20:330–335. <http://dx.doi.org/10.1016/j.clinbiomech.2004.11.006>.
- Cebolla, E., Rodacki, A., Bento, P., 2015. Gait and cognition: a complementary approach to understanding brain function and the risk of falling. *Braz. J. Phys. Ther.* 2:146–151. <http://dx.doi.org/10.1111/j.1532-5415.2012.04209.x>.
- Center for Disease Control and Prevention, 2015, March 19. Older Adult Falls: Get the Facts. Retrieved from www.cdc.gov/homeandrecreationsafety/falls/adultfalls.html.
- Cho, J., Smith, M.L., Shubert, et al., 2015. Gait speed among older participants enrolled in an evidence-based fall risk reduction program: a subgroup analysis. *Front. Public Health* 3 (26). <http://dx.doi.org/10.3389/fpubh.2015.00026>.
- Cook, D.B., O'Connor, P.J., et al., 2007. Functional neuroimaging correlates of mental fatigue induced by cognition among chronic fatigue syndrome patients and controls. *NeuroImage* 36–1:108–122. <http://dx.doi.org/10.1016/j.neuroimage.2007.02.033>.
- Dubost, V., Kressig, R.W., et al., 2006. Relationship between dual-task related changes in stride velocity and stride time variability in healthy older adults. *Hum. Mov. Sci.* 25: 372–382. <http://dx.doi.org/10.1016/j.humov.2006.03.004>.
- Fischer, B.L., Gleason, C.E., et al., 2014. Declining cognition and falls: role of risky performance of everyday mobility activities. *J. Am. Phys. Ther. Assoc.* 94:355–362. <http://dx.doi.org/10.2522/ptj.20130195>.
- Gamble, J.G., Rose, J., 1994. *Human Walking*. Williams & Wilkins, Baltimore, Maryland.
- Gardiner, M., Eisen, S., et al., 2009. *Training in Pediatrics*. Oxford University Press, Oxford, New York.
- Granacher, U., Bridenbaugh, S.A., et al., 2011. Age-related effects on postural control under multi-task conditions. *Gerontology* 57:247–255. <http://dx.doi.org/10.1159/000322196>.
- Hall, C.D., Echt, K.V., et al., 2011. Cognitive and motor mechanisms underlying older adults' ability to divide attention while walking. *Phys. Ther.* 91:1039–1050. <http://dx.doi.org/10.2522/ptj.20100114>.
- Hanson, E.E., Beckman, A., et al., 2010. Effect of vision, proprioception, and the position of the vestibular organ on postural sway. *Acta Otolaryngol.* 130: 1358–1363. <http://dx.doi.org/10.3109/00016489.2010.498024>.
- Hashimoto, M., Takashima, Y., et al., 2014. Dual task walking reveals cognitive dysfunction in community-dwelling elderly subjects: the Sefuri brain MRI study. *J. Stroke Cerebrovasc. Dis.* 23:1770–1775. <http://dx.doi.org/10.1016/j.jstrokecerebrovasdis.2014.05.008>.
- Herman, T., Mirelman, A., et al., 2010. Executive control deficits as a prodrome to falls in healthy older adults: a prospective study linking thinking, walking, and falling. *J. Gerontol.* 10:1086–1092. <http://dx.doi.org/10.1093/gerona/gdq077>.
- Holtzer, R., Shuman, M., Mahoney, J., Lipton, R., Verghese, J., 2011. Cognitive fatigue defined in the context of attention networks. *Neuropsychol. Dev. Cogn. B Aging Neuropsychol. Cogn.* 18 (1):108–128. <http://dx.doi.org/10.1080/13825585.2010.517826>.
- van Iersal, M.B., Kessels, R.P.C., et al., 2008. Executive functions are associated with gait and balance in community-living elderly people. *J. Gerontol.* 63-A (12), 1344–1349.
- Jalali, M.M., Gerami, H., et al., 2015. Balance performance in older adults and its relation-

Notice the formatting here. There are nice examples of using et al. and what to do if the author's last name starts with 'van'. You need to pay attention to the order of information and the formatting.

Author is Last name, First Initial.

Author and year of publication are divided by a comma.

Titles

The article title is not upper case but the journal title is. Neither is italicized. The journal title is abbreviated and includes the volume colon page numbers and the doi.

The publication or retrieval information includes the volume but not the issue number and the page numbers. Notice the colon and the fact that no abbreviated p or pp. is used. Note the doi.