10-27-2022

Peripheral Display in Virtual Reality Environments involves Higher Cognitive Demands Compared to Centered Display during Dual-Tasking

Moncef Bouzar

Marquessa Bryce

Segny Castillo

Damian Cortez

Olivia Doucette

See next page for additional authors

Peripheral Display in Virtual Reality Environments involves Higher Cognitive Demands Compared to Centered Display during Dual-Tasking

Moncef Bouzar[1], Marquessa Bryce[1], Segny Castillo[1], Damian Cortez[1], Olivia Doucette[1], Bayron Garcia[1], Andy Ho[1], Kara Ito[1], Chris Kim[1], Kelly Lansdell[1], Rahul Soangra[1 & 2]
[1]Department of Physical Therapy, Crean College of Health and Behavioral Sciences, Chapman University, Irvine CA 92618 USA
[2]Fowler School of Engineering, Chapman University, Orange CA 92866 USA

Peripheral displays may require higher attention allocation compared to centered displays. This study investigated how cognitive load with peripheral dual-tasking affected gait variability in healthy young adults compared to centered dual-tasking. Eleven healthy young adults (23.8±1.25 years) participated in the experiment. Participants performed three trials of three different tests while walking on the treadmill. The tasks were randomly assigned as i) normal walking without dual tasking, ii) walking with a centered cognitive arithmetic test or centered dual-tasking (DTC) and iii) walking with peripheral cognitive arithmetic test or peripheral dual-tasking (DTP). Gait parameters were evaluated for all three task conditions. We found step width significantly increased during DTP compared to the control walking condition ($p<0.05$). Our results revealed that DTP was challenging even for healthy young adults and thus leading to adaptations in step width. Our results show that DTP has clinical diagnostic values in revealing subtle gait deviations and can potentially be used to assess Parkinson's disease and post-concussion disorders.

Introduction

With changing world, humans are becoming more dependent on modern technology. Dual tasking and its relation with fall risk become a cause for concern since cell phone use during walking is a large part of one's day. Distractions can disrupt and alter gait, putting people at a greater risk of falling (Nascimbeni et al., 2015). Understanding the effects of dual-tasking can provide insight into the risk of falls in everyday life during walking. Sensory information, specifically visual perception, is essential during walking. Visual input dictates foot placement and head and trunk movements (Kimura & van Deursen, 2020). A simultaneous attention-demanding task may interfere with external visual cues that are used to regulate gait stability and posture (Kimura & van Deursen, 2020). An additional cognitive load placed on the individual requires further division of attention resources needed for walking (MacAulay et al., 2017). It is a common misconception that being at risk of falling only applies to those of older age. It is not, however, uncommon for healthy young adults to fall. The cause of falls in healthy young adults is most commonly attributed to balance and gait impairment. 38.9% of falls occur due to a balance or gait impairment (Osama et al., 2020). Nevertheless, among older adults, unintentional falls are the leading cause of injury-related deaths (Kannus, 1999).

There are several differences between young and older adults regarding gait characteristics and dual tasking. For both populations, studies have shown altered gait speeds, reduced cadence, shorter stride length, increased stride duration, and longer double-support time (Soangra & Lockhart, 2017). Older individuals may have more significant deviance in gait than younger individuals during dual-tasking. More substantial reductions in speeds have been reported in older populations while performing a cognitive task such as counting by seven (Springer et al., 2006). As such, 25% of U.S. residents above 65 report falling each year (Fritz et al., 2015). According to a study conducted by Hausdorff et. al., healthy young and older adults walk with about the same minimal amount of gait variability, despite gait speed being slower in healthy older adults than in healthy young adults (Hausdorff et al., 1997). It has been suggested that fall risk has a more significant relationship with gait variability than gait speed (Maki, 1997). Yet, no strong relationship has been drawn between fall risk and dual tasking during ambulation (Bloem et al., 2006). It can, however, be noted that the type of dual-task test can influence gait differently (Beauchet et al., 2005). Such findings fuel the need to understand the discrepancy between whether dual-tasking negatively affects gait and increases fall risk.

Previous research provides contradicting conclusions, for example, cognitive-motor interference, such as mobile technology, has been suggested to alter gait, putting young people at a greater risk of falling (Nascimbeni et al., 2015). Conversely, our previous research indicates that adaptations made during dual-tasking improve proprioceptive awareness, thus minimizing the risk of a fall. In such cases, participants are noted to adopt Cautious Gait Mode, which includes reduced walking speed, shorter step length, increased step width, and reduced heel contact velocity (Soangra & Lockhart, 2017). Our focus was to understand the change in the aforementioned gait parameters with increasing cognitive demand by incorporating a novel task involving random peripheral displays and solving arithmetic functions, known as Dual Task Peripheral (DTP) test. The DTP test offers a new outlook on challenging cognitive capacity during dual-tasking. By looking at variability in gait, clinical inferences can be made about ambulation in the real world.

While dual-tasking alone does not generally pose great difficulty to young, healthy individuals, a DTP test can be challenging enough to detect subtle changes in gait. Likewise, peripheral displays and high cognitive loading using arithmetic can make this test an ideal challenging assessment even for healthy young adults. Ambulation with an attention-demanding task introduces competition for attention resources, impacting gait-associated cognition function to successfully perform the task (Woollacott & Shumway-Cook, 2002). This study investigated gait variability and fall risk with increased cognitive load and peripheral displays than centered displays in young, healthy adults. It was hypothesized that peripheral display dual-tasking would impose higher cognitive demands than centered display dual-tasking.

Methods

Eleven healthy young adults participated in the dual-tasking experiment with six females and five males (age 23.8 ±1.25 years). Twenty-three motion capture markers were placed on bony landmarks: 1 sternum, 1 xiphoid, 1 navel, 1 at T10, 2 anterior superior iliac spine (right and left), 1 sacral, 2 greater trochanters (right and left), 2 front thigh (right and left), 2 lateral knee (right and left), 2 anterior tibia (right and left), 2 lateral malleolus (right and left), 2 at the fifth metatarsal (right and left) and 2 large toe (right and left) (Figure 1). The markers were used to evaluate spatiotemporal gait parameters such as step width, step length, stride length, stride time, step time, stance time, swing time, walking speed, cadence, single support, initial double support, terminal double support and total double support. For each leg (right or left): stance time, swing time, stance percent, swing percent, single support percent, step length, and step time were also measured. Each participant signed the written consent form before participation in the study. Anthropometric data, including participant height and weight was collected (Table 1). All participants were secured using an overhead harness during walking trials. The participant's preferred walking speed was determined and all trials were collected at this treadmill belt speed. Participants were instructed to answer the arithmetic questions displayed on the virtual reality screen as accurately as possible. The participants were randomly assigned to the three walking test conditions. The subject walked on the treadmill at their preferred walking speed for one minute with either i) no cognitive loading (Control), ii) centered arithmetic questions in front of them (Dual Task centered-DTC), and iii) peripheral arithmetic questions that changed location after five seconds (Dual Task Peripheral display -DTP) (Figure 2). Each walking condition was performed with three trials, and a break of one minute was provided in between each trial.

Table 1: Anthropometric data of all participants

Subject Gender	**Number of participants**	**Average Height (cm)**	**Average Weight (kg)**
Male	5	174 cm	82.7 kg
Female	6	163.8 cm	60.1 kg

An experimenter marked a tally for each incorrect verbal answer (arithmetic computation result). The participant answered 14 arithmetic questions during each trial. Percent error was quantified by dividing the number of wrong answers by each person's number of arithmetic questions during each trial.

Figure 1: Shows marker placement at several body landmarks

Results

We found step width was statistically different through the main effects test ($p < 0.05$) (Table 3). Post Hoc analysis revealed that step width increased significantly in DTP compared to control condition (Figure 3).

Table 2. Gait parameters across various tasks: control, Dual Task Centered (DTC) and Dual Task Peripheral (DTP).

Parameter	**Control (Mean ± SD)**	**DTC (Mean ± SD)**	**DTP (Mean ± SD)**	**F Ratio**	**Prob > F**
Stance to Swing ratio	65.86 ± 1.90	65.59 ± 2.03	66.15 ± 2.37	1.4994	0.226
Stance Time	0.74 ± 0.07	0.72 ± 0.06	0.75 ± 0.08	2.3872	0.0947
Step Length	0.64 ± 0.08	0.63 ± 0.15	0.6 ± 0.15	2.4333	0.0906
Step Time	0.56 ± 0.05	0.55 ± 0.04	0.57 ± 0.05	2.3873	0.0948
Step Width*	0.16 ± 0.03	0.17 ± 0.03	0.17 ± 0.03	4.5202	**0.0121***
Stride Length	1.27 ± 0.15	1.26 ± 0.31	1.19 ± 0.31	2.2802	0.1051
Stride Time	1.12 ± 0.09	1.1 ± 0.07	1.12 ± 0.09	2.0463	0.1321
Swing Time	0.38 ± 0.03	0.38 ± 0.03	0.38 ± 0.03	0.2215	0.8015

We found that the percentage error on cognitive arithmetic tasks was 2.27% fewer errors in DTP than in DTC (Figure 4). Though there was a difference in average percentage error, a t-test showed the differences were not statistically significant ($p > 0.05$). Average percentage errors during DTC and DTP were compared where the percentage error of DTC (24.68%) was higher than DTP (22.40%).

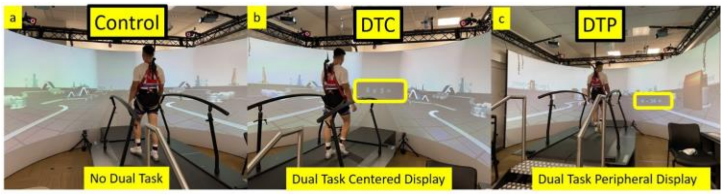

Figure 2. Picture showing 3 walking conditions a) Control- no dual-tasking, b) Dual task-centered at the visual display, c) Dual-task on the peripheral display.

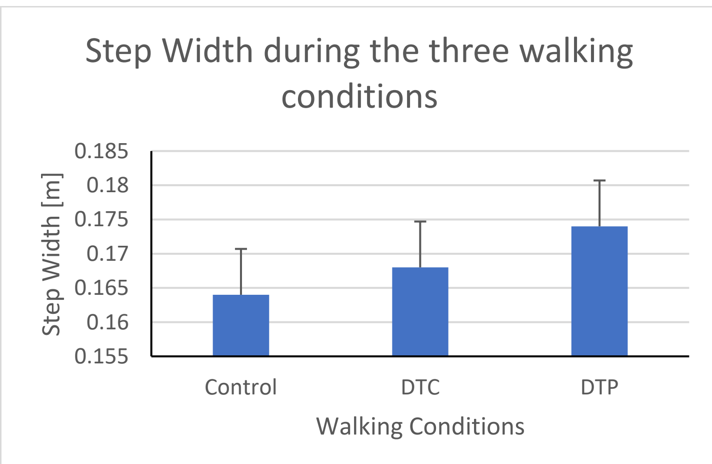

Figure 3. Step width during the three walking conditions (Control, DTC and DTP)

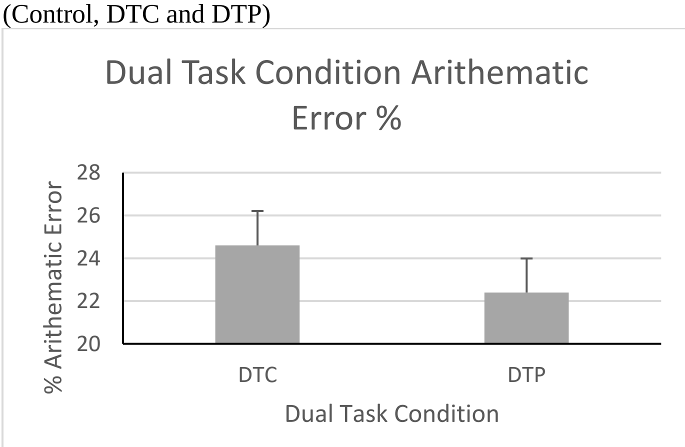

Figure 4. Average Percentage Error made during DTC and DTP tasks

Discussion

This study investigated the effects of peripheral displays during dual-tasking among young, healthy adults. Some of the prior research did not find any influence of dual-tasking on stability and gait during specific tasks for healthy young adults (Kimura & van Deursen, 2020; Nascimbeni et al., 2015; Nordin et al., 2010). Dual tasking with arithmetic questions and side-to-side cranial movements during peripheral display was developed to exhibit gait changes in healthy adults. It is hypothesized that as the cognitive load will affect step width and that the accuracy for the arithmetic task would be directly correlated to deviance from normal walking parameters. We found that step-width increased significantly during DTP trials compared to the control trials. These results demonstrate that increased cognitive demand during DTP increased step width for better stability (Table 2). Post Hoc analysis using Tukey's HSD revealed that the step width during DTP was significantly higher than control (Table 2). These results coincide with our previous findings that there is no destabilizing effect in healthy individuals on slip responses and gait during gait changes in dual task walking and an increase of stride width (Soangra & Lockhart, 2017). Despite no evidence of slip-related fall risk, DTP is effective for associating gait changes in step-width in adaptation to impending fall risk. Previous reports found variability in step-width while dual-tasking to be related to future or previous falls (Nordin et al., 2010). Step width has been previously suggested to be associated with specific walking components such as balance and walking stability (Decker et al., 2016).

In this study, the difference in arithmetic errors in DTP and DTC was not significant ($p=0.12$). However, fewer errors were made during DTP tasks (22.40%) than during DTC testing (24.68%). Although the differences between trials were insignificant, there was an inverse relationship between increased accuracy of cognitive tasks and gait variability, as stated in the hypothesis. We found an increase in step width and a decrease in arithmetic error during DTP, while during DTC, the step width did not change significantly compared to the control condition. This may be attributed to participants' higher cognitive demands during DTP and gait adaptations. A study conducted by Decker et al. cited young and older adults prioritizing cognitive tasks over gait (Decker et al., 2016). Even though gait is automatic, dual tasking requires attention to cognitive and motor components (Kimura & van Deursen, 2020). Therefore, the complexity of cognitive loading during dual-task walking can reveal any difficulty in the brain's executive function in switching between tasks, impacting cognitive or gait performance (Nordin et al., 2010).

In the meta-analyses by Chu (Chu et al., 2013) and Al-Yahya (Al-Yahya et al., 2011), step-width was a significant factor in determining fall risk in elderly populations. In contrast, other gait measurements played little to no role. Similarly, the present study's findings measured many gait variables but found step width to be the single statistically significant factor. The trials involving DTP presented similar results to the conclusions of Chu (Chu et al., 2013) and Al-Yahya (Al-Yahya et al., 2011), which highlighted internal interference (such as mathematics) as a significant factor adversely affecting gait via step width. Previously, a correlation has been reported between the future risk of falling and variability in step width and similar gait parameters (Nordin et al., 2010). Understandably, step width during gait is directly correlated to the base of support and, ultimately, balance (McAndrew Young & Dingwell, 2012). The increased fall risk associated with DTP can be clinically applied to most populations but is best adapted for those suffering cognitive deficits (Jeon et al., 2015). This can be inferred through a culmination of systematic reviews involving dual task performance with Parkinson's disease, neurological disorders and concussions (De Freitas Tb Ms et al., 2020; Fritz et al., 2015; Kleiner et al., 2018; MacAulay et al., 2017; Raffegeau et al., 2019).

Task prioritization is an additional performance factor to be considered when comparing cognitively fit participants. Healthy adults without any cognitive deficits can allocate attention to complete complex tasks such as those seen in the DTC and DTP tasks (Maclean et al., 2017). However, in some diseases like Parkinson's disease, patients adopt a "posture second" strategy when dual-task walking (Yogev-Seligmann et al., 2012). The "posture second" strategy is an approach to dual-tasking in which the subject equally values posture and completion of the task, as opposed to "posture first" which prioritizes stature and minimizes fall risk (Bloem et al., 2006). We found that DTP challenges cognitive and motor function significantly among healthy individuals by adapting step width, which lends to using DTP as a tool for recognizing fall risk in measuring gait variability.

Detection of subtle gait deviations can help the objective identification of post-concussion deficits under dual-task conditions (Howell et al., 2020). This may be attributed to dual-task walking correlating neural mechanisms subserving attentional cognition and gait (Smeeton et al., 2021). Implementation of DTP could potentially provide a new way to specifically analyze gait correlating to post-concussion injuries and aid in diagnosing concussions in young adults due to step width allowing clinicians to associate the component to balance control (Decker et al., 2016). Therefore, dual tasking requires concurrent execution of cognitive and motor tasks, allowing clinicians to measure patients' abilities during a similar sports-like demand than to single tasks (Howell et al., 2020). Earlier concussion research has utilized measures that quantify gait variability dysfunction, such as stride width (Howell et al., 2020). DTP could create ideal cognitive and motor task conditions to test for balance and fall-risk post-concussion. Although healthy individuals have a high cognitive capacity, this test may be able to detect subtle gait disorders such as a limp. Since high cognitive tasks and peripheral changes force individuals to focus on the task instead of correcting their injury, the injury may become exasperated while conducting DTP. This can be seen when participants conducting the DTP had less arithmetic errors, but experienced more gait variability in step width.

Although gait cycle deviations produced by dual-tasking have been studied in the past, this study aimed to explore the effects of peripheral displays during dual-task walking among healthy young people. Moreover, the current methods of producing gait deviations focused on using cognitive loading challenges centered in front of the participant's field of vision. This method did not create a difficult challenge to have a statistically significant deviation in the gait of healthy young individuals in prior studies. The most important result in our study was variability in step width between the control and peripheral cognitive load. Therefore, when the results are coupled with the results of other studies that show that variability in step width and fall risk are positively correlated in young healthy individuals, it can be inferred that healthy young individuals can be at risk of falling in specific scenarios such as texting and walking (Howell et al., 2020; Nordin et al., 2010). The potential fall risk in young, healthy individuals produced through cognitive loading provides the opportunity to test and compare fall risk in different age populations before injuries or at the onset of neurological disorders. Peripheral dual tasking has proved to be a challenging and sensitive method to measure potential fall risk in young, healthy individuals. The results of this study have opened a path for further research and, ultimately, clinical application. Future research can build upon these findings by using the presented study method with a larger population composed of individuals from all age groups and further observing the relationship between DTP and gait deviations.

References

Al-Yahya, E., Dawes, H., Smith, L., Dennis, A., Howells, K., & Cockburn, J. (2011). Cognitive motor interference while walking: a systematic review and meta-analysis. *Neurosci Biobehav Rev*, *35*(3), 715-728. https://doi.org/10.1016/j.neubiorev.2010.08.008

Beauchet, O., Dubost, V., Aminian, K., Gonthier, R., & Kressig, R. W. (2005). Dual-task-related gait changes in the elderly: does the type of cognitive task matter? *J Mot Behav*, *37*(4), 259-264. https://www.ncbi.nlm.nih.gov/pubmed/15967751

Bloem, B. R., Grimbergen, Y. A., van Dijk, J. G., & Munneke, M. (2006). The "posture second" strategy: a review of wrong priorities in Parkinson's disease. *J Neurol Sci*, *248*(1-2), 196-204. https://doi.org/10.1016/j.jns.2006.05.010

Chu, Y. H., Tang, P. F., Peng, Y. C., & Chen, H. Y. (2013). Meta-analysis of type and complexity of a secondary task during walking on the prediction of elderly falls. *Geriatr Gerontol Int*, *13*(2), 289-297. https://doi.org/10.1111/j.1447-0594.2012.00893.x

De Freitas Tb Ms, P. T., Leite, P. B., Dona F PhD, P. T., Pompeu Je PhD, P. T., Swarowsky A PhD, P. T., & Torriani-Pasin C PhD, P. T. (2020). The effects of dual task gait and balance training in Parkinson's disease: a systematic review. *Physiother Theory Pract*, *36*(10), 1088-1096. https://doi.org/10.1080/09593985.2018.1551455

Decker, L. M., Cignetti, F., Hunt, N., Potter, J. F., Stergiou, N., & Studenski, S. A. (2016). Effects of aging on the relationship between cognitive demand and step variability during dual-task walking. *Age (Dordr)*, *38*(4), 363-375. https://doi.org/10.1007/s11357-016-9941-y

Fritz, N. E., Cheek, F. M., & Nichols-Larsen, D. S. (2015). Motor-Cognitive Dual-Task Training in Persons With Neurologic Disorders: A Systematic Review. *J Neurol Phys Ther*, *39*(3), 142-153. https://doi.org/10.1097/NPT.0000000000000090

Hausdorff, J. M., Mitchell, S. L., Firtion, R., Peng, C. K., Cudkowicz, M. E., Wei, J. Y., & Goldberger, A. L. (1997). Altered fractal dynamics of gait: reduced stride-interval correlations with aging and Huntington's disease. *J Appl Physiol (1985)*, *82*(1), 262-269. https://doi.org/10.1152/jappl.1997.82.1.262

Howell, D. R., Bonnette, S., Diekfuss, J. A., Grooms, D. R., Myer, G. D., & Meehan, W. P. (2020). Youth With Concussion Have Less Adaptable Gait Patterns Than Their Uninjured Peers: Implications for Concussion Management. *Journal of Orthopaedic & Sports Physical Therapy*, *50*(8), 438-446. https://doi.org/10.2519/jospt.2020.9133

Jeon, S., Kim, C., Song, S., & Lee, G. (2015). Changes in gait pattern during multitask using smartphones. *Work*, *53*(2), 241-247. https://doi.org/10.3233/WOR-152115

Kannus, P. (1999). Fall-Induced Injuries and Deaths Among Older Adults. *JAMA*, *281*(20). https://doi.org/10.1001/jama.281.20.1895

Kimura, N., & van Deursen, R. (2020). The Effect Of Visual Dual-Tasking Interference On Walking In Healthy Young Adults. *Gait Posture*, *79*, 80-85. https://doi.org/10.1016/j.gaitpost.2020.04.018

Kleiner, M., Wong, L., Dube, A., Wnuk, K., Hunter, S. W., & Graham, L. J. (2018). Dual-Task Assessment Protocols in Concussion Assessment: A Systematic Literature Review. *J Orthop Sports Phys Ther*, *48*(2), 87-103. https://doi.org/10.2519/jospt.2018.7432

MacAulay, R. K., Wagner, M. T., Szeles, D., & Milano, N. J. (2017). Improving Sensitivity to Detect Mild Cognitive Impairment: Cognitive Load Dual-Task Gait Speed Assessment. *J Int Neuropsychol Soc*, *23*(6), 493-501. https://doi.org/10.1017/S1355617717000261

Maclean, L. M., Brown, L. J. E., Khadra, H., & Astell, A. J. (2017). Observing prioritization effects on cognition and gait: The effect of increased cognitive load on cognitively healthy older adults' dual-task performance. *Gait Posture*, *53*, 139-144. https://doi.org/10.1016/j.gaitpost.2017.01.018

Maki, B. E. (1997). Gait changes in older adults: predictors of falls or indicators of fear. *J Am Geriatr Soc*, *45*(3), 313-320. https://doi.org/10.1111/j.1532-5415.1997.tb00946.x

McAndrew Young, P. M., & Dingwell, J. B. (2012). Voluntary changes in step width and step length during human walking affect dynamic margins of stability. *Gait & Posture*, *36*(2), 219-224. https://doi.org/10.1016/j.gaitpost.2012.02.020

Nascimbeni, A., Minchillo, M., Salatino, A., Morabito, U., & Ricci, R. (2015). Gait attentional load at different walking speeds. *Gait Posture*, *41*(1), 304-306. https://doi.org/10.1016/j.gaitpost.2014.09.008

Nordin, E., Moe-Nilssen, R., Ramnemark, A., & Lundin-Olsson, L. (2010). Changes in step-width during dual-task walking predicts falls. *Gait Posture*, *32*(1), 92-97. https://doi.org/10.1016/j.gaitpost.2010.03.012

Osama, M., Waseem, M., & Imran, H. (2020). Fall risk and balance outcomes in healthy young adults: A call for research. *J Pak Med Assoc*, *70*(4), 769-770. https://doi.org/10.5455/JPMA.38023

Raffegeau, T. E., Krehbiel, L. M., Kang, N., Thijs, F. J., Altmann, L. J. P., Cauraugh, J. H., & Hass, C. J. (2019). A meta-analysis: Parkinson's disease and dual-task walking. *Parkinsonism Relat Disord*, *62*, 28-35. https://doi.org/10.1016/j.parkreldis.2018.12.012

Smeeton, N. J., Wrightson, J., Varga, M., Cowan, R., & Schafer, L. (2021). Coordination between motor and cognitive tasks in dual task gait. *Gait & Posture*, *85*, 138-144. https://doi.org/10.1016/j.gaitpost.2021.01.012

Soangra, R., & Lockhart, T. E. (2017). Dual-Task Does Not Increase Slip and Fall Risk in Healthy Young and Older Adults during Walking. *Applied Bionics and Biomechanics*, *2017*, 1-12. https://doi.org/10.1155/2017/1014784

Springer, S., Giladi, N., Peretz, C., Yogev, G., Simon, E. S., & Hausdorff, J. M. (2006). Dual-tasking effects on gait variability: the role of aging, falls, and executive function. *Mov Disord*, *21*(7), 950-957. https://doi.org/10.1002/mds.20848

Woollacott, M., & Shumway-Cook, A. (2002). Attention and the control of posture and gait: a review of an emerging area of research. *Gait Posture*, *16*(1), 1-14. https://doi.org/10.1016/s0966-6362(01)00156-4

Yogev-Seligmann, G., Rotem-Galili, Y., Dickstein, R., Giladi, N., & Hausdorff, J. M. (2012). Effects of explicit prioritization on dual task walking in patients with Parkinson's disease. *Gait Posture*, *35*(4), 641-646. https://doi.org/10.1016/j.gaitpost.2011.12.016