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## COGNITIVE SCIENCE & NEUROSCIENCE | RESEARCH ARTICLE

# Changes in cognitive load and effects on parameters of gait

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**Abstract:** Reading or texting with a mobile phone while walking requires cognitive resource allocation and consequently induces changes in gait. Fifty-six young adults walked along the GAITRite® walkway under baseline, low-, and high-cognitive loads. Participants' Functional Ambulation Profile (FAP), velocity, and stride length decreased while double-support time increased under higher cognitive load. This result shows that during cognitively loaded multitasking conditions participants are unable to stabilize their gait. In addition, lower FAP scores across the conditions suggest an increased risk for future injurious falls. This study demonstrates that distracted walking using a mobile phone can affect several parameters of gait and it would be prudent to not read or text on a mobile phone while walking.

**Subjects:** Attention; Cognitive Science; Cognitive Neuroscience

**Keywords:** cognitive resource allocation; cognitive load; dual task; gait changes; injurious falls

### 1. Introduction

Mobile phones are now considered a part of everyday life and being used by 91% of adults. Notably, 97% of young adults aged between 18 and 34 use mobile phones (Pew Research Center, 2013). According to the Statistics Portal (n.d.), the number of smartphone users in the United States has

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Chorong Oh is a doctoral candidate and Leonard L. LaPointe is a Francis Eppes distinguished professor in School of Communication Science and Disorders at Florida State University. They currently work in the Communication Neuroscience Laboratory (CNL). The CNL is a collaborative group of researchers and students at Florida State University and the Tallahassee Memorial Healthcare system who seek to understand and explore relationships between the brain and human communication and cognition. They are particularly interested in exploring cognitive-linguistic interactions (i.e. how attention, memory, and information processing support and interact with language and human communication). They are also interested in understanding and explaining brain disorders that cause communication and cognitive problems, conducting clinical research on questions related to brain, language, and cognition, and exploring how cognitive and communication factors impact other perceptual and motor system.

### PUBLIC INTEREST STATEMENT

Injurious falls are an enormous and increasingly prevalent risk aspect in both clinical and non-clinical populations. Surprisingly, injurious falls are not just caused by weakened muscles and/or impairments in motor system but also caused by higher levels of cognitive load. Everyone has limited attentional capacity. Therefore, people cannot fully concentrate on two or more things at a time. Instead they can change attention from one thing to another, which is facilitated by flexibility in attention. So when a person is in cognitively demanding situation such as texting on a mobile phone, he/she cannot walk safely and consequently is placed in a higher risk of injurious falls. The aims of the present study are to quantitatively measure the increased risk of injurious falls yielded by multitasking, here defined as walking and simultaneous reading or texting, and to investigate what specific parameters of gait are affected.

been increased from approximately 62.6 million in 2010 to 207.2 million in 2016 and is expected to reach 236.8 million by 2019 (<http://www.statista.com/statistics/201182/forecast-of-smartphone-users-in-the-us/>). With the increment of smart phone usage, concerns about pedestrian and driver safety have increased as well. The National Highway Transportation Safety Administration (NHTSA) reported that 38 percent of distracted drivers were using mobile phones in fatal crashes (NHTSA, 2016). Many studies revealed that the use of mobile phone when driving increases car accidents by distracting drivers. Implicated, as contributing factors for fatal crashes, are increased reaction time, narrowed view and several other measured decrements in driving performance (Caird, Willness, Steel, & Scialfa, 2008; Drews & Strayer, 2009; Drews, Yazdani, Godfrey, Cooper, & Strayer, 2009; Levy, Pashler, & Boer, 2006; Patten, Kircher, Östlund, & Nilsson, 2004; Strayer, Drews, & Johnston, 2003; Strayer & Johnston, 2001; Svenson & Patten, 2005).

The dangers of using mobile phone while walking have less dominated public attention. In spite of the studies that suggest that young adults are able to monitor and adjust their motoric behavior while walking and texting (Agostini, Fermo, Masazza, & Knaflitz, 2015; Bloem, Valkenburg, Slabbekoorn, & Willemsen, 2001), distracted attention during mobile phone use among pedestrians is well known. It threatens their safety as well as that of drivers (Nasar & Troyer, 2013). According to the U.S. Consumer Product Safety Commission (2015), emergency room visits due to distracted pedestrians while walking with mobile phones were up 124% in 2014 from 2006. Although walking may be more natural than driving, nearly 5,000 pedestrians were killed and 65,000 were injured in traffic accidents in 2014 (NHTSA, 2016). Nasar and colleagues (2008) found pedestrians were distracted and less aware of surrounding situations while walking and conversing on mobile phones. Hayman, Boss, Wise, McKenzie, and Caggiano (2010) confirmed this issue of distraction by pedestrians using mobile phones. Licence, Smith, McGuigan, and Earnest (2015) reported that texting and walking affected gait characteristics and yielded a more cautious gait pattern. Several other studies showed mobile phone users walked slower and deviated more in their path (Demura & Uchiyama, 2009; Hatfield & Murphy, 2007; Hayman, Boss, Wise, McKenzie, & Caggiano, 2010; Lamberg & Muratori, 2012; Schabrun, van den Hoorn, Moorcroft, Greenland, & Hodges, 2014).

Some suggested that walking and simultaneous mobile phone use including texting is risky due to physical demand (Marone, Patel, Hurt, & Grabiner, 2014) such as decreased arm swing (Bruijij, Meijer, Beek, & van Dieën, 2010; Hurt, Rosenblatt, & Grabiner, 2011; Pijnappels, Kingma, Wezenberg, Reurink, & van Dieën, 2010) while holding a mobile phone or interference was created by reduced vision (Hallems, Ortibus, Meirem, & Aerts, 2010; Timmis & Pardhan, 2012). However as Strayer et al. (2015) revealed that it was not a matter of physical restriction but rather an issue of simultaneous cognitive load, specifically distraction caused by mobile phone use. Other studies also have been in agreement with Strayer et al. (2015) suggesting that users of mobile phones while walking were subject to greater cognitive demands that affected cognitive resource allocation, and therefore these users missed more traffic signals or dangerous obstacles including cars (Hatfield & Murphy, 2007; Nasar et al., 2008; Schwebel et al., 2012; Stavrinos, Byington, & Schwebel, 2011).

In spite of those studies that provided evidence of the danger of using a mobile phone when walking, there still exists the need of more precise investigation of how parameters of gait change during simultaneous walking and mobile phone use with regard to cognitive resource allocation. Manipulating the complexity of cognitive load may affect parameters of gait during multitasking. Perhaps pedestrians will be impacted negatively by different levels of cognitive load. Kahneman (1973) proposed that human cognition is not unlimited. Instead humans allocate cognitive resource, which means cognitive processes are dependent on the availability of resources that can be devoted to task solution. Hence when the cognitive load given to a person is more demanding, the person cannot concentrate on other works as much. The limited capacity of human cognition can be explained and supported by Baddeley (2000, 2003). In 1974, Baddeley and Hitch proposed a three-component model of working memory. According to them working memory consists of three subsystems: the phonological loop, the visuospatial sketchpad, and attentionally limited control system. Baddeley (2000) then added a fourth component to the model, the episodic buffer. Finally in 2003, the

researcher proposed that working memory encompasses the temporary storage and cognitive activities require manipulation of information within the storage. Walking and simultaneous mobile phone use increases cognitive load due to the limited storage. With the increasing number of smart phone users, changes in mobile phone complexity means that pedestrians have more things to do with their mobile phones such as texting, reading, emailing, and listening to music. This trend causes issues of pedestrian safety accordingly. One of the issues is injurious accidents or falls that mobile phone use may trigger. Nasar and Troyer (2013) examined data from the National Electronic Injury Surveillance System for seven years from 2004 to 2010 involving mobile phone-related pedestrian injuries in public areas. They found that the number of mobile phone-related pedestrian injuries had risen every year since 2005 and reported several cases in the same study: A 14-year-old boy fell 6 to 8 feet off a bridge while walking on a road conversing on a mobile phone, suffering chest and shoulder injuries; a 28-year-old male walked into a pole while talking on a mobile phone and lacerated his brow.

It has been widely accepted that women are better at multitasking than men. One of the explanations for this difference is based on evolution and the Hunter-Gatherer Hypothesis that Silverman and Eals (1992) proposed has been attaining reputation. The hypothesis suggests that by developing their favored skills, men in hunting-related skills vs. women in gathering-related skills, as the results of natural selection, women became better at multitasking. Some other reports and books also suggest that women are better multitaskers than are men (Fisher, 1999; Pease & Pease, 2003).

Yet some researchers argue that scientific evidence for gender differences in multitasking is non-existent. Hambrick, Oswald, Darowski, Rench, and Brou, (2010) indicated that they were unable to find scientific evidence to support this view after an intense literature review. Mäntylä (2013) presented the opposite results. He indicated that gender difference was prominent only when the tasks involved spatial ability and men outperformed women. He interpreted this tendency as different spatial ability in men and women. In addition, Buser and Peter (2012) discovered that women suffer from multitasking as much as men when forced to multitask.

The purposes of this study, therefore, are as follows: (1) to investigate the effects of different levels of cognitive load on changes in ambulation and gait, (2) to explore how different types of simultaneous mobile phone use, in terms of cognitive resource allocation, affect spatial/temporal parameters of gait, particularly how they might be related to the risk of future injurious falls in neuro-typical young adults' walking, and (3) to investigate gender difference in simultaneous walking and mobile phone use.

## 2. Methods

### 2.1. Participants

Sixty-one neurotypical young adults agreed to participate in the current investigation voluntarily and data from 56 participants were used. Data from 5 among 61 were excluded due to missing data or because a participant's primary language was not English. The age range was from 19 to 45 years of age ( $M = 23.16$ ,  $SD = 4.72$  years) and included 22 males and 34 females. Table 1 contains

**Table 1. Demographic description and clinical characteristics**

Variables	Male	Female	Total
	<b>N = 22</b>	<b>N = 34</b>	<b>N = 56</b>
Age Mean yrs (SD)	24.86 (6.30)	22.06 (2.94)	23.16 (4.72)
Education Mean yrs (SD)	16 (1.02)	16.12 (1.25)	16.07 (1.16)
MoCA Mean (SD)	27.95 (1.62)	28.31 (1.39)	28.11 (1.49)

**Figure 1. GAITRite® Walkway.**



additional demographic and clinical information regarding age, education, and scores on the Montreal Cognitive Assessment (MoCA) scores included to rule out mild cognitive impairment.

### **2.2. Instrumentation**

To analyze parameters of gait, the GAITRite® Portable Walkway System was employed. The GAITRite® System is a 16-foot electronic walkway with embedded sensors to record temporal and spatial parameters of gait. At intervals along the length of the walkway, there are eight sensor pads encapsulated in a carpet that produces an active area of 24 inches (wide) and 192 inches (long). In this arrangement, an active array of 48 sensors by 384 sensors is placed on .5 inch centers for a total of 18,432 embedded sensors (Figure 1).

The walkway measures, interprets, and documents gait parameters using the accompanying GAITRite® software. As participants complete walks along the walkway, 14 spatial parameters and 24 temporal parameters from each footfall (Left and Right) are recorded and converted to quantitative results for each gait trial.

### **2.3. Procedures**

Upon completion of an informed consent form, each participant's overall cognition skills were measured using the MoCA test. Participants completed nine walk trials under three conditions of cognitive load. The baseline or control condition established typical gait pattern of walking along the mat with no simultaneous cognitive or linguistic task. The low-load condition consisted of walking across the walkway while reading participants' choice of material such as Facebook, email, or newspaper articles on their mobile phone. Participants were instructed to complete the low-load condition as naturally as they do in daily life: open reading material, scroll it down, stop scrolling and start to read when they found something interesting. The high load called for walking across the walkway during simultaneous texting. Under the high-load condition, participants were instructed to text their answer to the question, "What is your plan for this weekend?" All participants were asked to turn off "auto-correct" function and the number of words and mistakes in their texts was measured. Each of the conditions was completed three times and descriptive statistics were established for the condition. The order of presentation of the cognitive load conditions was counterbalanced to equally distribute potential order effects across conditions.

### **2.4. Variables**

The independent variables used for this study were two: cognitive load and gender.

The dependent measures analyzed for gait included the specific parameters of Functional Ambulation Profile (FAP), stride length, step velocity, and double-support time.

In the present study, we employed the FAP score developed by Nelson (1974). This algorithm derived from data collected on the GAITRite® system is widely used to predict future injurious falls. Since Nelson (1974) developed the algorithm, Nelson and colleagues took a prospective long-term tracking observation of the people who participated in the study of Nelson (1974). Nelson et al. (1999) reported that people who were at a lower FAP score ended up going to the emergency room or being hospitalized due to injurious falls. The FAP scoring system incorporates temporal and spatial parameters of gait to provide a quantitative and objective means of gait assessment (Nelson et al., 2002). Gretz and colleagues (1998) reported the FAP scoring system of the GAITRite® system was reliable. In addition, Gouelle (2014) reviewed the use of the FAP score for the evaluation of gait based on peer-reviewed articles and clinical experience. It was found that in the nondisabled adult population, the score ranged from 95 to 100. Nelson et al. (1999) also revealed that the FAP score ranges from 95 to 100 in healthy adults and decreased FAP score would mean a potential future injurious fall. After obtaining FAP scores across several demographic samples, Nelson and colleagues followed the participants prospectively and were able to identify those who had injurious falls and associate it clearly with their past lower FAP scores.

The GAITRite® Manual defines stride length as the line of progression between the heel points of two consecutive footprints of the same foot, measured in centimeters. Velocity was calculated by dividing the distance traveled, by ambulation time and the result was expressed in centimeters per second. The duration of time each participant was stabilized on two feet for each walk completed on the walkway was expressed as percent double-support time. In daily-life ambulation the spatial-temporal parameters of stride length, velocity, double-support time as well as the combination of parameters used to determine the FAP are all aspects of walking that are manipulated by people to monitor, maintain, and stabilize balance and myriad parameters of ambulation.

### 2.5. Analysis

To analyze the data collected for this present study, the IBM® SPSS Statistics® Version 22 was employed. Descriptive statistics were calculated to examine the distribution characteristics of the participants for each of the dependent variables. To address the research questions, inferential statistics that compared the performances were conducted. Specifically, a two-factor repeated measures analysis of variance (RMANOVA) with a within-subject factor of cognitive load (baseline, low load, and high load) and a between-subjects factor of gender (male and female) was conducted to examine the effects of mobile phone usage on the parameters of gait performance.

## 3. Results

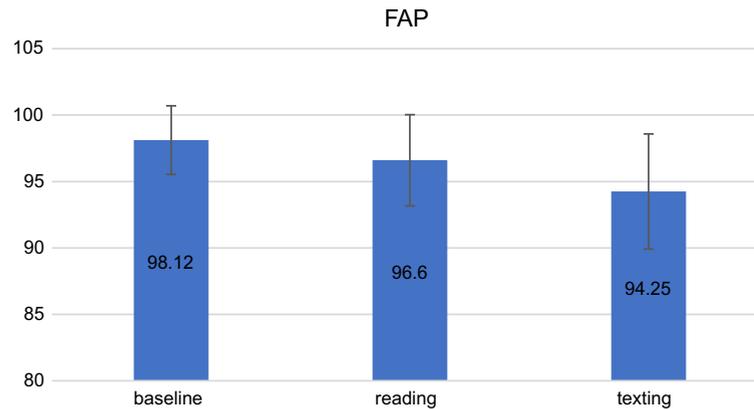
### 3.1. MoCA

Mean MoCA score of the participants was 28.11 (SD = 1.49, Range 25–30). Total possible score of the test is 30 and a score of 26 or above is within normal limits. Although there were four participants who scored a 25 on the test, each of these outliers was considered through report and observation to be within normal limits cognitively. These participants who scored 25 on the screening device demonstrated no signs of mild cognitive impairment and functioned normally in their academic lives and the researchers considered them to be within normal limits and the lowered score might have been due to momentary inattention or slight confusion on the test.

### 3.2. FAP

Data were analyzed using a two-way Repeated Measure ANOVA (RMANOVA) with a within-subject factor of cognitive load (baseline, low load, and high load) and a between-subjects factor of gender (male and female). Mauchly's test indicated that the assumption of sphericity was violated ( $\chi^2(2) = 28.01, p < .001$ ), therefore degrees of freedom were corrected using Greenhouse–Geisser estimates of sphericity ( $\epsilon = .71$ ). Main effect of cognitive load on FAP was revealed significant ( $F(1.42,$

**Figure 2. FAP with standard error.**

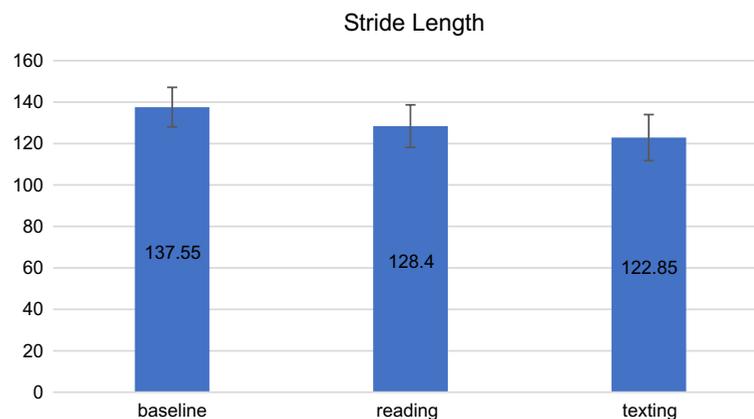


76.57) = 49.109,  $p < .001$ ,  $\eta p^2 = .476$ ). However, neither the effects of gender ( $F(1, 54) = .081$ ,  $p = .777$ ,  $\eta p^2 = .001$ ) nor the interaction between cognitive load and gender was found significant ( $F(1.42, 76.57) = 11.701$ ,  $p = .133$ ,  $\eta p^2 = .039$ ). The pairwise comparisons for the main effect of cognitive load using Bonferroni adjusted alpha levels of .016 showed that there were significant differences between the baseline ( $M = 98.12$ ,  $SD = 2.58$ ) and the low-load ( $M = 96.60$ ,  $SD = 3.43$ ) conditions ( $p < .001$ ), between the low-load and the high-load ( $M = 94.25$ ,  $SD = 4.33$ ) conditions ( $p < .001$ ), and finally between the baseline and the high-load condition ( $p < .001$ ). (Figure 2)

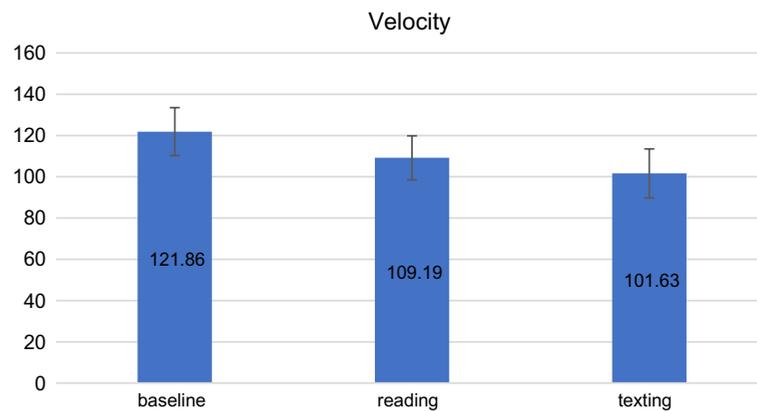
### 3.3. Stride length

The RMANOVA with the same within-subject and between-subjects factors yielded following results. Mauchly's test addressed that the sphericity was not assumed ( $\chi^2(2) = 25.22$ ,  $p < .001$ ), consequently Greenhouse-Geisser corrected degrees of freedom were used ( $\epsilon = .73$ ). Corresponding to the result of FAP, main effect of cognitive load on Stride Length (SL) was significant ( $F(1.45, 78.34) = 151.247$ ,  $p < .001$ ,  $\eta p^2 = .737$ ). As in FAP there was no significant difference according to gender ( $F(1, 54) = 10.493$ ,  $p = .087$ ,  $\eta p^2 = .163$ ). Furthermore, no significant interaction between the two factors ( $F(1.45, 78.34) = 1.715$ ,  $p = .193$ ,  $\eta p^2 = .031$ ) was found. Pairwise comparisons for SL after Bonferroni correction ( $\alpha = .016$ ) demonstrated significant decrements in SL between the baseline ( $M = 137.55$ ,  $SD = 9.35$ ) and the low-load ( $M = 128.40$ ,  $SD = 10.27$ ) conditions ( $p < .001$ ), between the low-load and the high-load ( $M = 122.85$ ,  $SD = 11.09$ ) conditions ( $p < .001$ ), and between the baseline and the high-load conditions ( $p < .001$ ). (Figure 3)

**Figure 3. Stride length (cm) with standard error.**



**Figure 4. Velocity (cm/s) with standard error.**



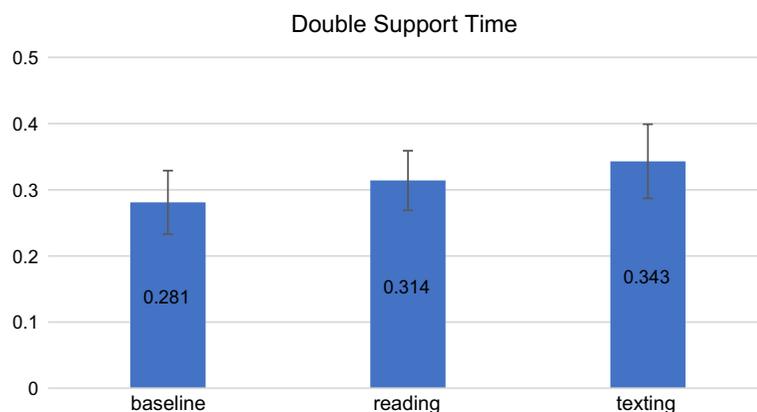
### 3.4. Velocity

The same RMANOVA was used to investigate performance on Velocity. The assumption of the sphericity was violated as in the other analyses ( $\chi^2(2) = 32.36, p < .001$ ), thus ensuing Greenhouse–Geisser corrected degrees of freedom were used ( $\epsilon = .69$ ). Analyses for Velocity of gait revealed a similar result. Main effect of cognitive load on this variable was robust ( $F(1.37, 74.13) = 125.745, p < .001, \eta p^2 = .700$ ) but gender ( $F(1, 54) = .090, p = .765, \eta p^2 = .002$ ) did not show a significance. In addition, gender by cognitive load interaction ( $F(1.37, 74.13) = 6.810, p = .101, \eta p^2 = .112$ ) was found meaningless as well. Consistent with the other variables, pairwise comparisons for Velocity after Bonferroni correction ( $\alpha = .016$ ) presented that participants' walking velocity decreased across the conditions. Specifically, baseline ( $M = 121.86, SD = 11.66$ ), low-load ( $M = 109.19, SD = 10.67$ ), and high-load ( $M = 101.63, SD = 11.89$ ) conditions were significantly different from each other ( $p < .001$  for each comparison) (Figure 4).

### 3.5. Double-support time

To analyze performance on Double-Support Time (DST), degrees of freedom were corrected using Greenhouse–Geisser estimation ( $\epsilon = .67$ ) due to the result of Mauchly's sphericity test ( $\chi^2(2) = 35.70, p < .001$ ). The analyses for DST yielded parallel results. As with the other dependent variables, main effect of cognitive load on DST was evident ( $F(1.34, 72.48) = 95.597, p < .001, \eta p^2 = .639$ ). No significant difference was revealed when gender was considered ( $F(1, 54) = 18.068, p < .001, \eta p^2 = .251$ ). The interaction between cognitive load and gender on DST was not significant ( $F(1.34, 72.48) = 5.998, p = .091, \eta p^2 = .100$ ). The pairwise comparisons after Bonferroni correction with adjusted alpha levels of .016 indicated that DST of participants significantly increased across the conditions. DST on baseline ( $M = .281, SD = .048$ ), low load ( $M = .314, SD = .045$ ), and high load ( $M = .343, SD = .056$ ) were significantly different from each other ( $p < .001$  for each comparison) (Figure 5).

**Figure 5. Double-support time (s) with standard error.**



#### 4. Discussion

The purpose of this investigation was to examine the effects of cognitive load on selected parameters of gait during simultaneous mobile phone walking and texting as well as to explore possible gender differences in walking and simultaneous mobile phone use. For this investigation, 56 young adults participated in the experiments voluntarily and conditions included 3 different cognitive loads. These conditions were baseline, reading while walking, and texting while walking. Conclusions warranted from this study include the following:

- Reading or texting on a mobile phone influences several parameters of walking. Participants' FAP, velocity, and stride length decreased significantly under conditions of higher cognitive load while their double-support time increased significantly. This result reveals that during these cognitively loaded multitasking conditions participants are unable to maintain walking speed or stabilize their gait.
- Manipulating the complexity of cognitive load affects parameters of gait during multitasking. Participants in this study were impacted negatively by the low- and high-cognitive load. As Kahneman (1973) proposed, impact on cognitive resource allocation skills were apparent and the participants allocated more cognitive resources to the reading and texting task than to walking. Among the two tasks, simultaneous texting was interpreted as a higher cognitive load evidenced by lower FAP score, shorter stride length, slowed walking speed, and longer double-support time.
- Motor efficiency is influenced and negatively affects gait to the point where there appears to be an increased risk of injurious falls. This result is supported by lower FAP scores across the conditions. In the current study, the FAP score was the lowest (94.25) during simultaneous walking and texting. It may not be low enough to assure the potential risk of injurious falls based on the findings of Gouelle (2014). Yet it is evident that when the cognitive load was higher, the FAP score was significantly lower meaning the participants were at a greater risk of potential injurious falls.
- No gender differences were found for any of the dependent variables. Gender differences in multitasking have been a controversial topic. The results of this current study support the studies that suggested performances of men and women are not different in multitasking. Multitask behavior requires cognitive resource allocation and consequently elicits prioritization of one task (Beauchert et al., 2009; Herman, Mirelman, Giladi, Schweiger, & Hausdorff, 2010; Kahneman, 1973; Schabrun et al., 2014; Segev-Jacobovskii et al., 2011; Yogeve-Scligmann, Hausdorff, & Giladi, 2012). Thus when multitasking, the tasks that were not prioritized receive less attention, which is the result of limited capacity of working memory (Baddeley, 2000). Oberauer and colleagues (2007) defined working memory as a system for attention to memory. In accordance with their definition of working memory, Pass and Sweller (2012) indicated that cognitive load theory is based on the limited capacity and duration of the human working memory. They suggested in the same study that cognitive load effects can be found in the collective working memory, the human movement, and in embodied cognition.

This current study supports other studies of young healthy adults that report reading or texting superiority while walking with a consequent compromise to balance and gait stability. Slower walking and other impacted parameters of gait under dual-task conditions in this study may result from compensatory processes.

This study compared the impacts of reading and texting on a mobile phone on gait performances and revealed mobile phone use during concurrent walking affected cognitive resource allocation and changed parameters of gait during different levels of simultaneous cognitive loads. The current study may be limited in two ways: (1) Participants walked on a relatively short mat. (2) Participants were allowed to choose materials to read. Although this was intended to elicit the most natural condition for participants, some of the readings may have been more emotionally loaded. Nevertheless, our results offer and extend some support to what has been previously reported in the

literature: walking and simultaneous mobile phone use impacts gait stability. In the current study, significantly altered parameters of gait may be associated with the possibility of future injurious falls or other accidents. Our findings have the potential to yield increased understanding associated with distracted walking. Well-documented reports of pedestrian injuries and even deaths during walking while distracted by simultaneous mobile phone use include walking into cars, buses, falling into fountains, and even one report of falling over a cliff. Distracted walking can affect several parameters of gait including FAP. This extends the findings of previous studies and provides a clearer understanding of the specific aspects of gait that are impacted during distracted walking. It would be prudent to avoid reading or texting on a mobile phone while walking to reduce the risk of accidents or falls and preserve the safety of pedestrians.

This study extends previous findings to which spatial-temporal parameters of gait are implicated. However, the effect of dual-tasking or multitasking is reported to vary among individuals (Shipstead, Lindseay, Marshall, & Engle, 2014; Watson & Strayer, 2010). Therefore, further studies with various samples under diverse dual-tasking or multitasking situations are warranted.

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#### Competing Interests

The authors declare no competing interest.

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