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Full length article

## Visual scanning behavior during distracted walking in healthy young adults

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## ARTICLE INFO

## Keywords:

Gait  
Cognition  
Vision  
Attention  
Texting

## ABSTRACT

**Background:** An epidemic of pedestrian accidents when walking while texting suggests that people are less aware of their surroundings during distracted walking, and highlights the importance of visual scanning for pedestrian safety. Quantitative examination of visual scanning during distracted walking is still lacking.

**Research question:** Is visual scanning behavior altered by distracted walking in healthy young adults?

**Methods:** We compared visual scanning behavior in 20 young adults during usual (single-task) walking, walking while performing a letter-fluency task, and walking while texting. Visual scanning behavior was measured by fixation count and dwell time percentage in specific areas of interest. Dual-task effects on gait speed, letter fluency, texting speed and accuracy, and situational awareness were also examined.

**Result:** Visual scanning behavior differed between the three walking conditions. During dual-task letter fluency, participants had significantly more non-walking path fixations than either of the other two conditions (i.e., more frequent, broader visual scanning). Conversely, during dual-task texting, gaze was focused predominantly on the phone, with little visual scanning of the walking path and surrounding environment. When walking without texting or talking, gaze was directed equally to far walking path and surrounding environment.

**Significance:** Texting while walking is associated with a considerable reduction in overt visual attention to the walking path and surrounding areas. Whether this translates to reduced conscious awareness of environmental stimuli remains unclear. Performing a verbal task while walking was associated with more frequent, wider visual scanning behavior, which may be specific to the nature of the verbal task in this study.

## 1. Introduction

Walking while texting has been recognized as a pedestrian safety risk [1–3]. Dual-task texting is particularly challenging due to the use of visual resources [4], cognitive processing, and manual activity. These competing demands lead to declines in walking speed [1,2,5] and texting speed and accuracy [5] relative to single-task performance. Furthermore, walking while texting results in reduced visual attention to one's surrounding environment (i.e., situational awareness), with young adults noticing fewer obstacles compared to undistracted walking [3,6]. Reduced situational awareness may contribute to accidents and injuries during distracted walking [3,7], but has not yet been quantitatively examined. Moreover, the existing literature has mostly studied situational awareness during distracted walking in laboratory settings or virtual environments [2,6,8,9], which may not accurately reflect performance in the real world. Unlike the laboratory, the real world is characterized by a dynamic, unpredictable environment that requires continuous monitoring to ensure safe navigation.

The purpose of this study was to examine how different types of distracted walking affect visual scanning behavior in healthy young adults. We compared visual scanning behavior by examining the number of visual fixations (i.e., sustained gaze on a single location), and dwell time percentage (i.e., proportion of time scanning including saccades and fixations within one designated location), during three different walking tasks: single-task walking, walking while texting, and walking while performing a phonemic letter-fluency task. The letter-fluency task is a cognitively-demanding task that does not involve the competing visual demands experienced during texting. We hypothesized that young adults would have fewer fixations within the walking path and surrounding environment while texting than the other two conditions, and that visual scanning during the dual-task letter fluency condition would also be reduced relative to single-task walking, due to relatively greater attentional demands. We also examined the dual-task effects on gait speed, phonemic letter fluency response rate, and texting speed and accuracy.

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<https://doi.org/10.1016/j.gaitpost.2018.10.017>

Received 3 August 2018; Received in revised form 25 September 2018; Accepted 14 October 2018

0966-6362/ © 2018 Published by Elsevier B.V.

## 2. Methods

### 2.1. Participants

The sample comprised 20 healthy young adults (18–30 years old), fluent in English, and who were regular users of a touch-screen Smart Phone, familiar with text-messaging, and able to walk independently for at least 10 minutes. Participants were ineligible if they reported a history of medical illness, hospitalization, or vestibular dysfunction in the last 3 months, current or previous neurological disease or injury, uncorrected visual or hearing impairment, lower extremity amputation, and any pain or other condition that could affect walking or Smart Phone use. Demographic information, typical cell phone usage, and texting habits were collected via questionnaires. The Institutional Review Board approved all research procedures and participants provided written informed consent. Participants were compensated \$25.

### 2.2. Procedures and instrumentation

All procedures were conducted in a real-world setting (hospital lobby). The lobby was a busy pedestrian thoroughfare, with visitor information desks, waiting areas, and escalators on the right; and a hospital entrance and a furnished sitting area alongside floor-to-ceiling glass windows on the left. Each walking trial was videotaped and later analyzed for the number of pedestrians. Participants completed three walking trials: (1) usual walking at self-selected speed (single-task), (2) walking while texting (dual-task texting), and (3) walking while simultaneously performing a phonemic letter-fluency task (dual-task letter fluency). Texting and letter fluency were also performed in sitting (single-task). Task and condition order were block-randomized across the participants. During dual-task conditions, no specific instructions were provided regarding task prioritization.

For the texting task, we used the iPhone application, “MySpeed” (GenialApps, 2011©). Participants completed a minimum of 5 seated practice trials for familiarization with the texting task and interface. All participants used the same iPhone (iPhone 5). The texting software presented a textbox beneath a written phrase that the participants were instructed to type as quickly and as accurately as possible, using a standard iPhone keyboard. Phrase length was standardized to 2 lines across participants. Participants were alerted by phone vibration and text color change when they had made an error. Errors had to be corrected manually; the software did not allow autofill or autocorrect. To ensure only dual-task strides were captured in dual-task trials, participants were instructed to stop walking as soon as they completed typing the phrase. The texting software computed texting speed (characters per minute [CPM]), error rate (%), and trial duration (s), which were recorded for each trial.

The phonemic letter-fluency task required participants to state as many unique words as possible that began with a particular letter of the alphabet in one minute. The participants completed one seated practice trial, responding to the letter F. The practice trial also served to determine difficulty level for the experimental trials. If the participant generated: (1) > 18 words with the letter F, the letters N and G were assigned, (2) 11–18 words, the letters L and R were assigned, and (3) < 11 words, the letters M and S were assigned [10,11]. Order of the assigned letter pair was randomized and counterbalanced. We computed correct response rate (words per minute [WPM]).

The gait task involved continuous walking along a 60-m walkway (firm, multicolored tile surface) in the hospital lobby. Gait speed (m/s) was measured by computing the distance walked (tracked with a measurement wheel) over trial duration (recorded with a stopwatch).

The participants wore Natural Gaze™ Eye Tracking Glasses (ETG) (SensoMotoric Instruments, Boston, MA) during all conditions to record visual scanning behavior. The glasses recorded the environment from the participant’s viewpoint using a high-definition scene camera (30 Hz) as well as the gaze behavior of the participant (spatial accuracy

of  $0.1^\circ$  visual angle  $\pm 0.5^\circ$ ) using an infrared camera aimed at each eye (60 Hz).

Three areas of interest (AOI) were defined to analyze visual scanning during walking tasks: near-walking path, far-walking path, and non-walking path. Near- and far-walking path areas were defined, respectively, as the walking path up to or beyond 20 feet of the participant. Walking path referred to the area of terrain along which the individual was walking or could deviate within to avoid collisions with other pedestrians or objects along the path. Non-walking path was defined as any space, object, or person (moving or stationary) outside the walking path. A fourth AOI (“phone”) was used only for the texting trials and was defined as any part of the phone.

### 2.3. Statistical analysis

The dependent variables for the primary analysis were dwell time percentage and visual fixation count. Dwell time percentage represents the duration of all visual fixations and saccades as a proportion of the total trial duration. A visual fixation was defined as 50 ms or more of continuous gaze, which was the default ETG setting for fixations, as used previously [12,13]. Only participants for whom at least 90% of the trial was successfully tracked with ETG eyewear were included in the analyses. This excluded only 1 participant from the primary analysis and 3 participants from the comparison involving the “phone” AOI. One further participant was excluded from the primary gaze analyses due to inability to calibrate the ETG over corrective glasses.

Fixation count and dwell time percentage data were not normally distributed for the path and non-path AOIs due to the high number of zero fixation counts in these AOIs during the texting task, because of the high rate of fixation on the phone in this condition. The data were unable to be normalized due to the high number of zero values. Since a nonparametric equivalent for the planned ANOVA was not possible, we analyzed the untransformed data. The texting accuracy data were negatively skewed, which was corrected with arcsine transformation.

Differences in visual scanning behavior between the three walking conditions were analyzed with a Condition (single-task gait, dual-task letter fluency, dual-task texting) x AOI (near-walking path, far-walking path, non-walking path) repeated measures ANOVA on dwell time percentage and fixation count, with Tukey’s HSD post-hoc tests as needed. We also examined differences in dwell time percentage and fixation count on the phone AOI between the single- and dual-task texting conditions. Differences in gait speed (m/s) between conditions were examined with a one-way repeated measures ANOVA, and paired sample t-tests compared single and dual-task values for texting speed (CPM), texting accuracy (% correct), and letter fluency response rate (WPM). Relative dual-task effects (DTE, %) on situational awareness (defined as total dwell time to path and surroundings), gait speed, and letter fluency (WPM)/texting performance (combined speed and accuracy) were calculated based on established convention [14,15] to enable observation of relative prioritization in each dual-task condition. Analyses were performed using SPSS 24.0 (SPSS Inc., Chicago, IL). Significance level was set at  $p \leq 0.05$ . With a sample size of 20, we could detect an effect as small as 0.09 m/s assuming a SD = 0.15 [5], correlation coefficient = 0.65 [5], alpha = 0.05, and power = 0.90.

## 3. Results

The participants were 20 young adults with a mean age of 25 (range 22–30) years, 55% female, 20% black, and 65% with some college education. Participant characteristics and media use are summarized in Table 1. On average, participants encountered 15 people (SD = 5) in the hospital lobby during the walking trials.

### 3.1. Visual scanning behavior

There was a significant Condition x AOI interaction for both fixation

**Table 1**  
Participant characteristics and media use (n = 20).

	Mean	SD
Gender, female [# (%)]	11 (55)	–
Age (years)	25.0	2.8
Education (years)	16.5	1.8
Handedness, right dominant [# (%)]	17 (85)	–
Wear corrective contacts/glasses [# (%)]	6 (30)	–
Ethnicity [# (%)]		
White/non-Hispanic	14 (70)	–
Black	4 (20)	–
Mixed	2 (10)	–
Usual cell phone type [# (%)]		
iPhone	12 (60)	–
Other touch-screen phone	8 (40)	–
Length of time with current phone (years)	1.9	0.9
Number of texts sent per day – weekday, weekend [# (%)]		
0-9	3 (15)	3 (15)
10-30	9 (45)	9 (45)
31-50	2 (10)	1 (5)
51-70	4 (20)	3 (15)
71-90	1 (5)	2 (10)
91-110	0 (0)	1 (5)
> 111	1 (5)	1 (5)
Percent of cell phone use (talking/texting) while walking [# (%)]		
1-25%	6 (30)	–
25-50%	9 (45)	–
50-75%	3 (15)	–
> 75%	2 (10)	–
Reported experiencing collision or near collision while texting and walking [# (%)]	16 (80)	–

count ( $p < 0.001$ ;  $\eta_p^2 = 0.35$ , Fig. 1A) and dwell time percentage ( $p < 0.001$ ;  $\eta_p^2 = 0.41$ , Fig. 1B). During dual-task letter fluency, participants had significantly more non-walking path fixations than in either of the other two conditions. There was no significant difference in near-walking path fixations across conditions, and the number of fixations in near-walking path was uniformly low across all conditions; participants were mostly gazing further ahead. Far-walking path fixation counts were lower during dual-task texting than either of the other two conditions, which did not differ from each other. During dual-task texting, mean fixation counts in near-walking path (< 1 fixation), far-walking path (< 5 fixations) and non-walking path (< 1 fixation) AOIs were negligible due to the high mean ( $\pm$  SD) fixation count on the phone (110.9  $\pm$  47.6).

Dwell time percentage in near-path was uniformly low and not significantly different between the three conditions. Dwell time percentage for both far-path and non-path was significantly lower in the dual-task texting condition than either of the other two conditions, which did not differ from each other. While texting, high average dwell

**Table 2**  
Mean (SD) for single-task and dual-task measures of gait speed, letter fluency, texting, and situational awareness (total dwell time percentage in walking path and surrounding environment).

	Single-task		Dual-task letter fluency		Dual-task texting	
Gait speed (m/s)	1.23	(0.15)	0.93	(0.18)	0.93	(0.15)
Letter fluency (WPM)	14.3	(3.2)	13.9	(2.9)		
Texting speed (CPM)	182.8	(67.1)			141.4	(41.2)
Texting Accuracy (% correct)	89.3	(10.4)			83.0	(13.6)
Situational awareness (% dwell time in environment and path)	81.1	(12.5)	78.8	(12.2)	3.3	(5.2)

time on the phone (86%  $\pm$  11) meant that dwell times in near, far, and non-path AOIs were considerably low (< 3%).

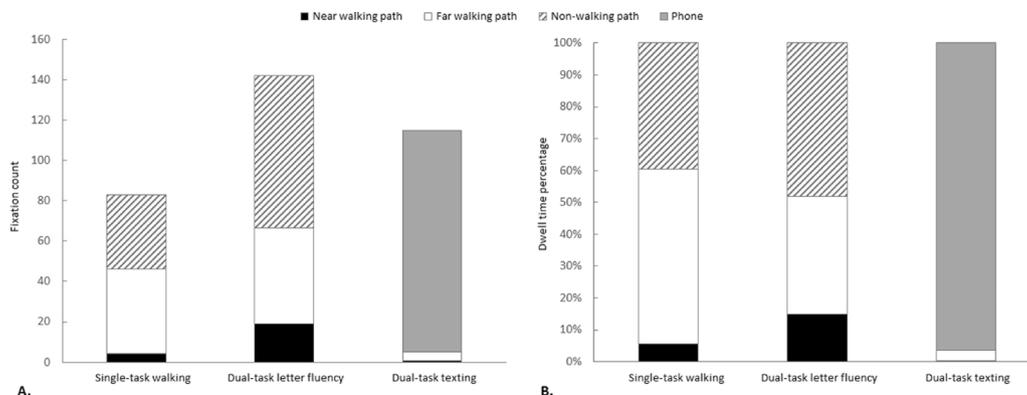
The mean fixation count on the phone while texting was higher in the dual-task (110.9  $\pm$  47.6) than the single-task condition (98.6  $\pm$  52.1;  $p = 0.03$ ,  $d = 0.58$ ) (Fig. 1A), but total dwell time percentage on the phone was lower during the dual-task (86.7%  $\pm$  10.6) than the single-task condition (94.5%  $\pm$  8.9;  $p = 0.003$ ,  $d = 0.85$ ) (Fig. 1B). We observed 4 near collisions in the dual-task texting condition, but not in any other condition. A near collision was defined as an abrupt, unplanned change in gait to avoid bumping into a person/object.

### 3.2. Gait speed, letter fluency, and texting

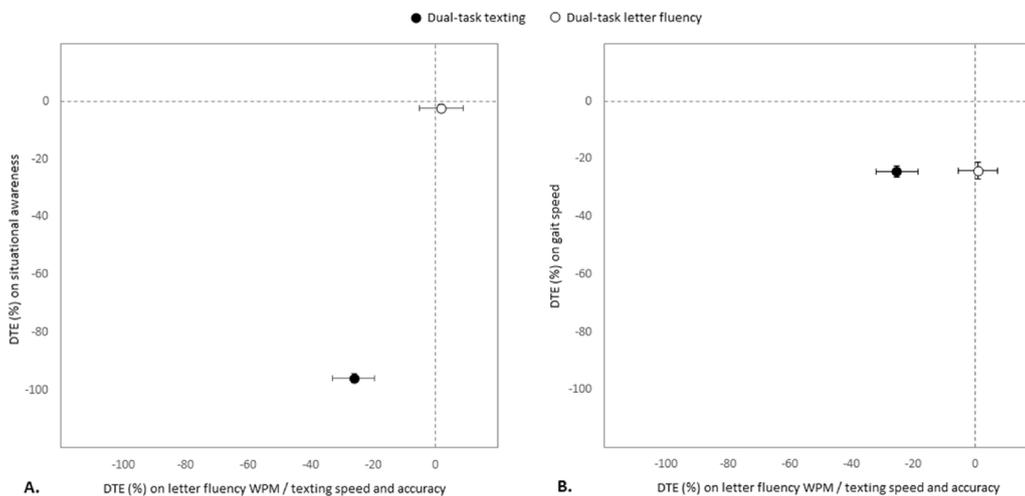
Gait speed was slower in both dual-task conditions than the single-task condition ( $p < 0.001$ ,  $\eta_p^2 = 0.77$ ; Table 2). There was no difference in gait speed between the two dual-task conditions.

Compared to single-task texting, during dual-task texting participants typed significantly fewer CPM while walking and texting ( $p = 0.002$ ,  $d = 0.80$ ; Table 2) and were less accurate ( $p = 0.003$ ,  $d = 0.77$ ). There was no significant difference in WPM for the letter-fluency task between the single-task and dual-task conditions.

During dual-task texting, there was pervasive prioritization of texting over situational awareness (Fig. 2A, Table 2), with a 96%  $\pm$  5.6 dual-task cost on total dwell time to walking path and surrounding environment relative to a 26.2%  $\pm$  30.9 dual-task cost on texting performance. However, when examining possible tradeoffs between gait speed and texting during dual-task texting, there was approximately equal mutual dual-task interference in the performance measures (Fig. 2B, Table 2). On average, there was a negligible dual-task effect on situational awareness during the dual-task letter fluency (Fig. 2A), and on letter fluency performance; only a dual-task cost (24.1%  $\pm$  12.6) on gait speed (Fig. 2B).



**Fig. 1.** Visual fixation count (A) and dwell time percentage (B) shown as a function of walking condition and area of interest. “Phone” area of interest was for texting task only.



**Fig. 2.** Relative dual-task effects (DTE) for letter fluency (WPM)/texting (combined speed and accuracy) and situational awareness (% total dwell time in environment and walking path) (A) and letter fluency/texting and gait speed (B). DTE values represent percent change in dual-task relative to single-task, where a negative DTE indicates that performance was worse in dual-task than single-task condition. Error bars are SEM.

**4. Discussion**

Our hypothesis that young adults would have fewer fixations in the walking path and surrounding environment during texting while walking was strongly supported by the data. In fact, there were fewer than 7 total fixations and less than 4% of total dwell time spent looking up from the phone while walking. Despite the reduced overt visual attention to the walking path, only 4 of the participants came close to a collision. This suggests that young adults may be storing information about their environment in memory to be able to navigate without the need to constantly monitor their surroundings. Another possibility is that they were using their peripheral vision to monitor their near environment. That is, they may be relying on non-central points in the visual field to avoid collisions when walking. Regardless, our findings verify previous observations of reduced situational awareness in young adults during texting while walking [16] and reiterate the importance of visual scanning for pedestrian safety. This study provides the first quantification of the extent of this reduced visual attention to the surrounding environment.

Despite the participants’ intense focus on the phone during walking, both texting speed and accuracy were significantly reduced relative to texting while sitting. This is probably a consequence of the need to occasionally glance up from the phone to check the path for obstacles and in-line navigation, which is supported by the finding that participants shifted their gaze on and off the phone more frequently during walking than when sitting. Increased need for memory resources may also explain dual-task costs on gait speed and texting. The current results demonstrate prioritization of texting over visual monitoring of the walking path and environment. This was confirmed by substantially greater dual-task costs on situational awareness (total dwell time in path and environment AOIs) than texting. Our finding of approximately equal mutual dual-task interference on texting performance and gait speed is consistent with previous research with young adults in a real-world setting [5].

Contrary to our prediction, visual scanning during dual-task letter fluency was not reduced relative to single-task walking. In fact, during dual-task letter fluency, participants scanned their environment more broadly and frequently, evidenced by more non-path fixations (i.e., surrounding environment) than in either of the other two conditions. Our findings are similar to those of Ellmers et al. [17] who found that healthy young adults visually fixated on task-irrelevant areas outside the walking path more often and for longer durations when walking while simultaneously carrying out a serial subtraction task compared to single-task walking. In the current study as well as in Ellmers et al. [17], the non-path fixations were accompanied by significantly reduced gait speed compared to usual walking. It is not clear if the slowed gait speed

is a consequence of the altered gaze or the attentional demands of the cognitive task, or both. It is possible that the greater non-path fixations in our study were due the nature of the task, such that participants were looking around for “clues” for the letter-fluency task (e.g., things starting with the letter N).

Unlike dual-task texting, in which we observed compelling prioritization of texting over situational awareness, there was no meaningful dual-task cost on either situational awareness or letter fluency performance in the dual-task letter-fluency condition. However, the absence of dual-task interference on letter-fluency performance in combination with an observed dual-task cost on gait speed suggests relative prioritization of the verbal task. The different attentional/prioritization strategies for the two tasks may be related to differing visual demands and relative complexity.

A critical assumption was that visual fixations on an AOI were indicative of where (or to what) a person was attending. Yet, we know that visual fixation is accompanied by covert intake of environmental information by peripheral vision, which may have included the near environment when focused on more distant fixation points, thereby reducing the need for near-point fixations (which were rare among our participants). Consistent with our findings, Turano et al. [18] found that individuals with normal vision spent the majority of time fixating ahead or at the goal of the walking task. Thus, it is possible that if participants did not “fixate” directly on an object, but the object fell within the field of view, it may have been perceived and accounted for in navigation planning. In a similar vein, covert attention and peripheral vision during texting may have provided our participants with sufficient awareness of their surroundings to navigate safely (albeit slower). Visual eye-tracking systems can reliably determine fixation points but fixation area alone may not be adequate to confirm which environmental information was deemed relevant and processed. Nonetheless, the drastic decrease in overt visual attention while texting is likely to have limited complete awareness of one’s surroundings, and may explain why pedestrians who are texting while walking experience so many accidents [3,7].

A potential limitation of this study is that we utilized the default setting of the ETG of 50 ms to define a visual fixation. There is currently a lack of consensus for the minimum duration to define a fixation sufficient for processing visual input [17,19–21], especially during ambulatory activities with and without attentional demands in real-world settings. For example, Poulton [21] suggested that 200 ms was the minimum fixation duration for defining cognitively meaningful visual fixations whereas, Manor et al. [20] found a threshold of 100 ms discriminated visual fixations from other oculomotor activity. This study is the first to provide insight into gaze behavior during walking in a real-world setting with and without added attentional demands.

Gait speed was chosen as the only gait variable because of known susceptibility to dual-task interference and the ability to make direct comparisons to previous texting studies. Additional parameters such as gait variability may provide more insight into gait adaptations during distracted walking.

## 5. Conclusion

Texting while walking is associated with a considerable reduction in overt visual attention to the walking path and the surrounding environment, which corroborates previous studies indicating that situational awareness is reduced among young adults during distracted walking [6,16]. Walking while performing a verbal task also alters gaze behavior, but does not appear to influence overall dwell time on one's surroundings. Future research will need to elucidate whether the altered gaze behavior during dual-task walking is associated with reduced awareness of environmental stimuli and hazard detection, which could have safety implications.

## Conflict of interest statement

The authors have no conflict of interest to declare.

## Authors contribution

Jody Feld: Conceptualization, Methodology, Validation, Formal Analysis, Investigation, Writing – Original Draft, Writing – Review and Editing, Visualization, Project Administration, and Funding Acquisition.

Prudence Plummer: Conceptualization, Methodology, Validation, Formal Analysis, Writing – Review and Editing, Visualization.

## Acknowledgements

This work was supported in part by a Promotion of Doctoral Studies Scholarship from the Foundation of Physical Therapy. The authors thank Alyssa Kappert for assistance with data collection and processing.

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