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Review

A narrative review of texting as a visually-dependent cognitive-motor secondary task during locomotion

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ABSTRACT

Typing while walking is an example of people's ability to interact with technology while engaged in real life activities. Indeed, an increasing number of studies have investigated the typing of text messages (texting) as a dual task during locomotion. The objective of this review is to (1) describe the task requirements of texting-while-walking, (2) evaluate the measurement and psychometric properties of texting as a dual task, and (3) formulate methodological recommendations for researchers who use and report on texting-while-walking. Twenty studies which used texting as a dual task during gait were identified via a literature search. The majority of these studies examined texting among young healthy adults and showed that, like other dual tasks, texting-while-walking caused decrements in both gait and texting performance. The cause of these decrements was most likely related to increased visual task requirements, task-dependent cognitive requirements and fine motor skills. Texting-while-walking gait measures were repeatable, but texting performance showed poor reliability which further depended on skill. Preliminary results show that texting-while-walking performance may discriminate between populations (e.g., young vs. older adults) but no studies have yet examined its predictive validity (e.g., for fall risk). In conclusion, texting-while-walking is an ecologically-valid dual task for locomotion which has become much more commonly used in recent years. As opposed to other secondary tasks such as subtraction by 7 or generating words, texting may challenge various cognitive, visual and sensorimotor domains depending on its content. This imposes task-specific methodological challenges on future research, which are discussed.

1. Introduction

Walking is a complex behavior requiring continuous sensorimotor integration of information and attention to the changing features of the environment [1]. This integration of different higher cognitive processes is jointly known as executive function [2]. When an additional task is added to walking (e.g., speaking, texting), deterioration in performance of one or both tasks (dual task interference) will occur when the tasks are performed concurrently [3]. McIsaac et al. [4] recently defined dual tasking as "*the concurrent performance of two tasks that can be performed independently, measured separately and have distinct goals*" (p. 2). Theories explaining dual task interference assert that it results from the two tasks using the same neural networks (Bottleneck Theory [5]), sharing the same capacity for attentional resources (Capacity-Sharing Model [6]) or using multiple resources which may compete for certain aspects of performance (Multiple Resource Theory [7]). While these theories may differ in their predictions for the origin of dual task interference [2], dual task interference during gait is a documented phenomenon that has been investigated since the 1980s [8]. Aside from its value as an evaluation tool, texting as a dual task is also important in everyday life since decrements in gait performance due to distraction may result in increased risk. For example, important visual cues on a street may be disregarded, leading to dangerous street crossing, or gait speed may decrease to a level which becomes non-functional (e.g., too slow to cross a street).

A plethora of studies have used various dual task paradigms to show that an additional task while walking impairs gait performance [9], specifically gait speed [10,11]. Recently, an increasing number of studies have used the typing of text messages (texting) on a mobile phone as the secondary task during gait. Texting while

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walking (TeWW; not to be confused with the acronym TWW for Talking While Walking) is becoming an increasingly common activity [12]. Indeed, in 2015, Americans exchanged 1.89 trillion text messages [13]. This accounts for the growing interest in studying TeWW using a dual task research paradigm. However, while "traditional" dual tasks are known to affect cognitive and/or sensorimotor performance, the characteristics of texting as a dual task for gait as well as methodological aspects of using this task are largely unknown. This review was written to address this concern by (1) describing the task requirements of TeWW, (2) evaluating the measurement and psychometric properties of texting as a dual task, and (3) formulating methodological recommendations for researchers who use and report on TeWW as a dual task.

In order to achieve these goals, a search of the literature was performed using combinations of the terms "walking", "phone", "mobile", "cell phone", "dual task" and "texting" in selected search engines (PubMed, CINAHL, Clinical Key, EMBASE). References within identified papers were examined as well. Only peer-reviewed journal articles published by February 2016 were included provided they involved an experimental task of simultaneous walking and *active* interaction with the screen of a mobile phone (i.e., typing or tapping rather than reading). Twenty studies were identified for this review; details are presented in Table 1. The

Table 1
Characteristics of studies (N = 20) assessing dual-task performance of texting (see details in text) and walking.

	References	Year	N[a]	Environment	Walking task	Gait outcomes	Texting task	Device	Texting outcomes[b]		Prioritization instructions	DTC of gait speed (%)[c]
									Speed	Accuracy		
1	Lin et al. [14]	2007	64 (16 in each condition)	Indoors	Treadmill and overground obstacle course	Gait speed	Tapping (with stylus) on targets on PDA	Personal Digital Assistant (PDA; e.g. tablet)	Time until tap on target	Percentage of taps which missed the target	No details	36.4
2	Demura & Uchiyama [15]	2009	30	Indoors	10 m walkway with/ without obstacle (measurement 5 m walkway)	Gait speed, stride length, stride width, stance phase duration	Asked to use email to answer a random personal question (e.g. food for lunch, mistakes in life, etc.)	Personal	X	X	No details	16.5 (female), 17 (male)
3	Lamberg & Muratori [16]	2012	33 (11 texting)	Indoors	8 m walkway Vision occlusion	Gait Speed, lateral deviation, linear distance traveled	Asked to type names of states, muscles, students, etc.	Unknown	X	X	No details	32.9
4	Lopresti-Goodman et al. [17]	2012	25 (13 texting)	Indoors	5 m walkway	Smallest doorway passed without turning, gait Speed	Asked to write a short sentence in each trial (15–21 characters)	Unknown	X	X	No details	25.3
5	Schwebel et al. [18]	2012	138 (in four groups)	Indoors	Virtual reality pedestrian environment – street crossing (treadmill)	Pedestrian variables (safety), looks away from street, etc.	Asked to answer texts received on the personal device	Personal	X	X	No details	–
6	Clawson et al. [19]	2014	36	Indoors	Following a pathway in the lab	–	Asked to write sentences presented on the screen	Blackberry	WPM	100*(1-total error rate)	No details	–
7	Parr et al. [20]	2014	30	Indoors	8 m walkway	Gait Speed, step width, DS time, toe clearance, step length, cadence	Asked to answer a general question ("name the colors of the rainbow in order")	Personal	X	X	No details	16.7
8	Schabrun et al. [21]	2014	26	Indoors	8.5 m walkway + additional experiment (N = 5) on treadmill	Gait speed, lateral deviation of foot, ROM and coordination of head pelvis and thorax	To type the sentence 'The quick brown fox jumped over the lazy dog' (after training for familiarity)	Personal	Correct words WPM	Proportion of correct words out of total (Autocorrect turned off)	No prioritization instructions provided	24.1
9	Kim et al. [22]	2014	33	Indoors	Ramp 5 m ascent or descent	Gait speed, cadence, stride length, step length, single support time, stride time, DS time	To text the words of a "song of patriotism"	Unknown	X	X	No details	29.0 (ascent), 31.3 (descent)
10	Agostini et al. [23]	2015	18	Outdoors	3 min walk in a 15 m path (back and forth)	Gait speed, cadence, stride length, DS time, CV stride time, muscle activation patterns	Asked to type a message describing their activities in	Personal	CPM	X	No prioritization instructions provided	10

Table 1 (*Continued*)

	References	Year	N[a]	Environment	Walking task	Gait outcomes	Texting task	Device	Texting outcomes[b]		Prioritization instructions	DTC of gait speed (%)[c]
									Speed	Accuracy		
							the previous day					
11	Kao et al. [31]	2015	7 young, 9 older	Indoors	Treadmill at self-selected speed, 2 min	Trunk local stability (local divergence exponent), dynamic margins of stability, knee and ankle angles, step length, step width, variability of spatiotemporal gait measures	Required to dial 10-digit numbers presented visually	Flip phone (Motorola Razor)	X	X	No details	–
12	Licence et al. [24]	2015	30	Indoors	Obstacle course	Gait speed, course time, Step frequency, step time, DS time, lateral deviation, obstacle clearance	Asked to answer texts received on their phone	Personal	X[e]	X	No details	21.8
13	Lim et al. [25]	2015	20	Indoors	Treadmill at 0.89m/s	Stride length, stride width, stride time, double support time, pelvis excursion and velocity, visual cue detection	Texting speed software on phone (random word sequence)	Galaxy S2	WPM	Percentage of correct words (Autocorrect turned off)	No prioritization instructions provided (use regular texting behavior)	–
14	Plummer et al. [26]	2015	32	Indoors	Lab and indoor walkway in a student center	Gait speed	Texting speed software on phone (random word sequence)	Iphone	CPM	Percentage of correct words (Autocorrect turned off)[d]	Prioritization to either task was requested as well as no prioritization	18.5 (lab), 16.3 (student center)
15	Plummer et al. [27]	2015	31	Indoors	Lab and indoor walkway in a student center	ICCs, SEM, MDC95 for gait speed	Texting speed software on phone (random word sequence)	Iphone	CPM	Percentage of correct words (Autocorrect turned off)[d]	Prioritization to either task was requested as well as no prioritization	15.8, 18.5 (two trials)
16	Strubhar et al. [28]	2015	32	Indoors	5 m walkway	Gait speed, cadence, DS time, base of support, step length	Asked to answer a random personal question ("where do you see yourself in 5 years?")	Personal	CPS	Number of errors in text	No prioritization instructions provided	17.8
17	Hamacher et al. [29]	2016	11	Indoors	Treadmill at 1.66 m/s for 3 min	Local dunamic stability (lyapunov exponents), test-retest ICCs	Asked to type a long text which was visible in front of the treadmill	Unknown	X	X	No details	–
18	Takeuchi et al. [32]	2016	16 young, 15 older	Indoors	Walking in a circle (radius 2.5m)	Step time, trunk acceleration peaks, activity of pre-frontal cortex	Number selection in ascending order, numbers presented on screen	iPod Touch 5	X	Errors in number selection	No prioritization instructions provided	–
19	Strouwen et al. [33]	2016	121 people with Parkinson's disease	Indoors	5 m walkway	Gait speed	Asked to type in the date	A phone with large buttons (Emporia talk premium)	X	Errors in date	No prioritization instructions provided	25.2
20	Banducci et al. [30]	2016	32	Indoors	Virtual reality pedestrian environment – street crossing (self-paced treadmill)	Success in street crossing, duration of the phases of street crossing, safety (time to contact with vehicles), percentage of time looking at the screen	Naturalistic conversation – asked to answer questions regarding movies seen, books read, personal details.	A tablet mounted on the treadmill	X[e]	X	No prioritization instructions provided	–

[a] Unless otherwise specified, population consisted of young healthy adults.
[b] CPM – Characters per minute, CPS – Characters per second, WPM – Words per minute. See text for details.
[c] When performance data were available, the dual task Cost (DTC) on gait was calculated according to the formula presented by Kelly et al. [50] . The DTC sign was adjusted according to the directionality of the outcome such that positive DTC values indicate a deterioration in performance.
[d] Speed and accuracy DTC were summed to create a global texting cost.
[e] This study evaluated gazes to the tablet (number and duration) and number of characters typed within each segment of street crossing and treated these variables as texting variables, although texting speed and accuracy were not evaluated.

majority of studies assessed dual task interference of TeWW in young healthy adults [14–30], two studies evaluated TeWW among young and older adults [31,32], and one study [33] described TeWW in people with Parkinson's disease.

2. Requirements of texting as a dual task

2.1. Visual requirements of texting

Walking invariably includes visual and/or auditory processing of stimuli arriving from the environment. When adding a dual task to gait, attention to external cues may decrease. For example, listening to music while crossing a virtual street increased the likelihood of getting hit by a car [18]. Texting during walking inherently generates a visual distraction [18] and competes for limited visual resources with other environmental cues which are often important for safe walking (i.e., observation of cars and streetlights). Indeed, Lim et al. [25] showed that 48.3% of the visual cues that were noticed when walking without texting, were ignored when texting. Schwebel et al. [18] showed that in a virtual pedestrian environment, texting resulted in more vehicular collisions during street crossing. In the same study, talking on the phone did not generate a similar effect, suggesting that the additional visual requirements of texting contributed greatly to the distraction. In both studies, the tasks required considerable visual attention (copying words from the screen [25] or answering text messages on the phone [18]). In fact, the visual requirements of TeWW appear to be so large that the cost of texting on overground gait speed is similar to that of walking overground with complete occlusion of vision [34]. Taken together, these data indicate that vision plays a significant role in the interference generated by a texting task, at least for healthy, young adults.

2.2. Cognitive requirements of texting

Dual tasks require varying levels of cognitive resources, and can thus be placed on a continuum of varying difficulty. For example, subtracting serial sevens entails a larger cognitive demand than subtracting serial threes. Increasing task difficulty is associated with larger dual task interference on gait speed, e.g. [12], as well as larger predictive ability of dual task performance, for example for fall risk in older adults [35]. However, increasing task difficulty may not be suitable for all, as the amount of interference generated when adding a dual task to gait also depends on personal characteristics such as age. Chu et al. [35] noted that the level of difficulty needs to be appropriate for the population; a task may be too difficult for a specific population (e.g. very old or institutionalized individuals) and may result in a floor effect and lack of predictive ability for those people [35,36]. In contrast, the same task may be too easy for a different population and not generate enough dual task interference for them. Thus, the selection of an appropriate dual task for a specific population is non-trivial; this may account for the fact that dual task walking is still not a standard for clinical assessment of fall risk in older adults [37].

Texting-while-walking studies involve a multitude of texting tasks, with varying levels of cognitive difficulty. The simplest texting-like task, which appears in the earliest paper [14] is tapping on targets on the screen of a tablet (or PDA). In later studies, simple texting tasks were copying numbers, words or sentences as they appeared on a screen [17,19,21,25–27,29,31]. More complex texting tasks required recall of actions or details (names, dates) to answer closed [33] or open-ended [15,16,20,22,23,30] questions. One study [24] used texting as a mental tracking task (e.g., typing the result of an arithmetic calculation on a mobile phone). In terms of cognitive demand, texting requires processing speed (for typing) and, in the case of a recall task, added challenges are reading comprehension, working memory and long-term memory [9].

Due to the diversity of texting tasks used in the various studies, determining how the level of task difficulty affects the dual task cost of texting on gait speed is problematic. To date, there are no studies directly comparing different texting tasks for the same subjects (see [38] for an auditory task). In addition, the level of detail provided by most authors for the tasks is limited. For example, the meaning of the words used in the texting task may affect semantic processing of the stimuli [39] and, consequently, change their attentional requirements. In the studies reported in this review, both the lowest and the highest dual task costs on gait speed among healthy young adults were measured using an open-ended recall task [16,23]. One study which compared two texting tasks (answering questions on the phone and solving math problems) found no difference in dual task cost between the tasks [24]. This suggests that cognitive task difficulty per se may *not* be the only factor determining dual task cost of texting on gait; rather other factors should be taken into consideration. A task which has low cognitive difficulty (such as copying words) likely requires more frequent glances at the screen and thus may generate a large interference with gait due to visual requirements (see Section 2.1). In addition, the content of the input and output (e.g., emotional responses vs. academic knowledge) may influence attentional resources needed for the task. Finally, as mentioned above, the characteristics of the population, e.g., age and cognitive abilities, may also affect the difficulty of the task and hence modify the dual task cost. None of these characteristics have been adequately investigated; only two studies evaluated TeWW in older adults [31,32] (and arrived at conflicting results) and only one study evaluated TeWW in a clinical population i.e., people with Parkinson's disease [33]. Importantly, since texting while walking has become more and more frequent in recent years, the cost of texting on gait may depend also on the amount of texting experience a person has. A more adept user of mobile technology may experience reduced cognitive load when texting and walking, and it can thus be expected that more recent studies will demonstrate a smaller dual task cost of texting. However, experience of the participants in texting was not always documented. A longitudinal study and/or use of a learning paradigm are needed to test this hypothesis.

An additional probe of the cognitive requirements of TeWW is direct measurement of the level of brain activation associated with its performance. Supporting the major role of executive functions in dual task gait performance, numerous recent studies have shown that walking while performing an additional cognitive or motor secondary task is associated with increased frontal lobe activation compared to single task performance (see [40] for a systematic review). Increased prefrontal activation is further associated with more demanding cognitive tasks (e.g., subtracting serial 7's versus forward counting [41]). To demonstrate this effect, near-infrared spectroscopy (NIRS) or electroencephalogram (EEG) technologies are typically used, as they are portable and, hence, may be used while walking. Indeed, one study [32] used NIRS to demonstrate an association between right and left prefrontal cortical activation and the dual task cost of smartphone use (playing a game) during walking among young and older adults. It did not, however, explore the relationship of task difficulty with frontal brain activation. It is to be noted that both NIRS or EEG have some methodological drawbacks of measuring brain activation during gait due to their low spatial resolution or possible movement artifacts. Thus care in interpreting results using these technologies is warranted.

Finally, an important factor for the extent of dual task interference generated by TeWW is task prioritization. Young adults, and to some extent healthy, older adults are able to modify dual task cost by flexibly prioritizing performance of either gait or the dual task added to it [42,43]. Regrettably, data regarding task prioritization are missing in 11 of the 20 papers evaluating TeWW (Table 1). Seven papers explicitly stated that no prioritization instructions were given. Refraining from provision of instructions may stem from an attempt to generate a more ecologically-valid task. Two articles from the same research group evaluated different prioritization instructions in young healthy adults (prioritize gait, prioritize texting, or no prioritization) [26,27]. These studies showed that young adults were able to flexibly prioritize gait and texting performance when instructed to do so, both in a lab setting as well as in a more ecologically-valid environment (a busy indoors, mall-like setting). It is unknown, however, whether other populations (older, clinical) are able to do this.

2.3. Sensorimotor requirements of texting while walking – gross and fine motor skills

A secondary motor task added to walking may shed light on difficulties encountered while performing concurrent motor activities in everyday life. A secondary motor task can entail gross or fine motor skills, or a combination of both, and may also involve manipulation of external objects. A common example of a gross motor task used as a secondary task while walking is carrying a glass of water or supporting a tray with glasses on it [44,45] (but see also [4] who suggest that this is not, in fact, a "dual task"). Some examples of fine motor tasks are finger tapping or finger opposition [46], buttoning a shirt [47] or moving coins between pockets [48].

Texting-while-walking is a motor task that entails both gross and fine motor skills. The gross motor skills include carrying a mobile phone, namely holding the phone with one or both hands instead of swinging the arms freely as typically occurs while walking [49]. Walking without arm swing does not generate significant gait alterations and a mobile phone is not considered to be a heavy load, with newer models weighing between 100 and 200 g. It is thus reasonable to assume that the gross motor skills required for walking while holding a mobile phone are not associated with dual task interference. Nevertheless, the phone used in seven of the 20 studies presented in this review was the subject's personal mobile phone such that the physical properties of the device (size, weight, etc.) were not controlled (in four studies these details were not reported). No study, to date, reported a comparison of walking with and without a mobile device in hand.

In addition to gross motor skills, the texting task requires fine motor skills. Specifically, finger dexterity (accurate finger placement and speed) is essential in order to avoid errors, as well as to complete the task within its time limits. Thus, deficits in tactile sensation or proprioception may further interfere with texting performance or generate increased reliance on vision.

3. Measurement and psychometric properties of texting as a dual task for locomotion

3.1. Measurement of walking and texting

Assessing task performance in TeWW requires, according to the dual-task research paradigm, the measurement of both walking and texting performance, as well as the dual task cost of each task [50]. In the absence of measurement of both tasks and their dual task cost (which may indicate the priorities given to each task by the subject) important information regarding the attentional cost of the dual task may be missing.

Gait measurement in the studies reviewed here was typical of other studies which used dual task paradigms [10], e.g., spatiotemporal gait parameters and variability of gait. A majority of TeWW studies (13/20) examined overground walking [15–17,19,20,22–24,26–28,32,33] while others (5/20) evaluated treadmill walking [18,25,29–31], and two studies [14,21] evaluated both treadmill and overground walking. Several studies also added more challenging gait conditions such as an obstacle course [15,24]. It can be assumed that the more frequent use of overground walking stems from the desire to maintain the ecological nature of the TeWW task. The use of these different test paradigms is a limitation in the ability to compare dual task costs across studies. For example, there are variations in gait outcomes, since the commonly used measure of gait speed is irrelevant on a treadmill that moves at a constant speed. Walking on a treadmill differs from overground walking also in the type of optic flow it generates [51], a fact that may be important when incorporating a visually-demanding dual task such as texting. The different task requirements of walking on a treadmill compared with overground walking may also modify task prioritization (see Section 2.2) in different populations, since overground stopping to walk has different implications than on a motorized treadmill. These issues merit further systematic investigation. Nevertheless, the existing literature demonstrates that dual task costs of TeWW exist both for overground and treadmill gait measures (Table 1).

In comparison with the standardized measures used to evaluate gait kinematics under single and dual task conditions, measurement of the texting tasks varied across the studies, probably due to the novelty and complexity of the task and the lack of standardized measures for it. Typically, texting performance measurement includes two outcomes: (1) texting speed and (2) accuracy (number of errors during typing). A trade-off exists between these two measures according to Fitts' law [52], such that increased speed is associated with reduced accuracy. Thus, both typing speed and error rate during texting should be reported since some users may type faster but make more errors during typing, while others may type more slowly and accurately. Eleven of the studies in this review did not report texting speed. One study [30] reported on the number of characters typed and the duration, but did not compute texting speed directly. One study reported reaction time for tapping [14], four studies reported texting speed using characters per minute (CPM) [23,26,27] or characters per second (CPS) [28] and three studies reported texting speed using words per minute (WPM) [19,21,25]. (Table 1). The transition between WPM and CPM is not straightforward since one has to estimate the mean number of characters in a word (in the English language this is usually 4 or 5 depending on whether spaces are calculated or not). This may be why a large range of texting speeds were reported in the studies – from 80 CPM [23] to 230 CPM [27]. Error rates were reported in nine studies. Of these studies, three reported absolute number of errors [28,32,33,53] and six reported the relative success rate [14,19,21,25–27]. In order to monitor texting accuracy, it is essential that the autocorrect function of the phone be turned off. This was reported in four out of the 20 studies [21,25–27].

A combined score of the dual task effect on accuracy and speed of typing was used in two studies from the same research group [26,27] who calculated the summed dual task cost of typing speed and typing accuracy to estimate the total cost of dual tasking. This type of comprehensive measurement is important as a means of accurately evaluating texting behavior.

3.2. Psychometric properties of texting-while-walking

The importance of studying the psychometric properties of dual tasks was stated by Yang et al. [54]. This is especially important since in recent years, dual task performance has become an outcome measure in intervention studies (e.g. [55]). Among the texting and walking studies reviewed here, studies evaluating psychometric properties have appeared since 2015, in line with Yang et al. [54].

3.2.1. Test-retest reliability and minimal detectable change

Test-retest reliability of texting was demonstrated by Hamacher et al. [29] who used an arithmetic subtraction task (serial sevens) as well as walking with and without texting in order to establish test-retest reliability of local dynamic stability of gait during these tasks. Test-retest reliability of local dynamic stability while walking and texting was fair to good (Intraclass correlation coefficients (ICCs) of 0.463–0.791). Lower values were found for the serial sevens task (ICCs of 0.052–0.575), suggesting that, in young healthy adults, TeWW may demonstrate a more consistent performance than other tasks due to its familiarity to users. Hamacher et al.'s [29] findings support those of Plummer et al. [27] who showed that test-retest reliability of gait speed and dual task cost of gait speed during texting was good to excellent (ICCs of 0.76–0.95) in young healthy adults, and that greater texting skill was associated with better reliability of task performance. In contrast, results from the same study showed that reliability of texting speed was fair to good (ICCs of 0.32–0.60), and texting accuracy and texting dual task cost had poor test-retest reliability (ICCs of 0.00–0.31), a finding which the authors associated with lower skill level of the texting task compared with walking. It should be noted, that outcomes derived from "traditional" cognitive dual tasks such as reaction time or mental tracking also suffer from lower reliability for the secondary task [56].

In addition to test-retest reliability, Plummer et al. [27] calculated the minimal detectable change (MDC_{95}, with 95% confidence) for gait speed and texting performance. Changes of over 11.9% in gait speed were considered to denote a real change, but due to the large variability in texting, only differences of >70% in texting performance were considered to be a real change.

3.2.2. Construct validity (convergent and discriminant)

Two studies compared texting with other dual tasks for gait. Kao et al. [31] performed a texting task (dialing numbers) added to treadmill walking, as well as two other cognitive tasks: a Paced Auditory Serial Addition Test (PASAT) [57] and a visual Symbol Digit Modalities Test (SDMT) [58]. Results demonstrated similar effects of texting and the visual task (SDMT) on gait parameters, but some differences between them and the auditory task (PASAT). Thus texting, which loads on the visual modality, generated similar effects to a visual dual task but not to an auditory dual task. These results need to be confirmed with a larger sample, as this study's sample size was relatively small (7 young and 9 older adults). Strouwen et al. [33] examined TeWW as well as two cognitive dual tasks (auditory Stroop task and a backwards digit span task) in a sample of 121 people with Parkinson's disease. Results showed that the texting task (typing the current date) generated a larger interference on gait speed, with a 25.17% decrease in gait speed compared to a mean decrease of 13.33% for the Stroop task and 14.68% for the digit span task. It is noteworthy that the same predictors of dual task performance (single task performance and executive function) were found for all three tasks despite the different modalities involved.

3.2.3. Construct validity (comparing dual task texting across populations)

A sensitive secondary task should be able to discriminate between the performance of different populations (e.g., young vs. older, healthy vs. clinical) [1]. To date, two studies [31,32] evaluated TeWW in older adults and arrived at conflicting results. While Kao et al. [31] showed no difference between young and older adults' dual-task gait performance, Takeuchi et al. [32] demonstrated larger decrements in older adults' gait performance in the dual-task condition compared to that of young adults. However, these two studies are difficult to compare, as Kao et al.'s [31] sample consisted of a "younger" older adults group (mean age 61 years) who walked on a treadmill. In contrast, Takeuchi et al.'s [32] sample consisted of an "older" group of older adults (mean age 71.7 years) who walked overground. In addition, the two studies measured different gait outcomes, which may account for dissimilarities in their discriminant ability.

3.2.4. Summary of psychometric properties

The number of studies that have examined the psychometric properties of TeWW is growing. To date, results demonstrate that some TeWW gait performance outcomes are more repeatable than others (e.g., gait speed vs. local dynamic stability). In comparison with gait, texting performance during TeWW shows lower test-retest reliability and larger minimal detectable change, which may limit its use as an isolated outcome measure. Similar to other dual tasks, texting performance depends on factors such as the user's skill. Some evidence suggests that the interference generated by texting may be similar to that of other vision-dependent secondary tasks. Furthermore, texting may discriminate between performance of young and older healthy adults. However, no studies to date have examined predictive validity of TeWW or the minimal clinically important difference. These two aspects of measurement psychometrics are essential in order to standardize texting as a secondary task for gait, as either an evaluation tool or, possibly, as an intervention protocol in rehabilitation settings.

4. Discussion and recommendations

"Traditional" dual tasks for gait typically require relatively isolated cognitive and sensorimotor abilities. In contrast, texting is a complex secondary task that requires extensive visual, motor and cognitive resources that likely account for the considerable dual task interference it imposes. Indeed, the studies identified in this review suggest that TeWW generates significant alterations in the gait pattern compared to walking alone (Table 1).

The main advantage of texting is that it is a verisimilitude-based task, i.e., it is similar to everyday activities [1] and thus intuitive to perform, especially for young healthy adults. In addition, TeWW may serve as a test-case for the ability of people to interact with technological environments while engaged in real life activities. Recent developments in mobile gaming (e.g., Pokemon Go by Nintendo [59]) suggest that this interaction is complex and may lead to hazardous consequences. Indeed, the distraction associated with mobile device use among pedestrians is increasingly associated with injuries [12]. In addition, an important goal for use of dual tasks during gait is to identify older adults who are more prone to falling [35] and TeWW may be able to do so in the future. However, despite the constantly growing pool of evidence, barriers still exist before dual tasks are adopted as evaluation protocols in clinical practice (e.g., to identify fall risk) [37]. Unlike more established dual tasks, the predictive ability of TeWW to detect fall risk has not yet been demonstrated.

In the future, TeWW may be used, as is the case with other dual tasks, in rehabilitation settings as an intervention aimed to improve dual task abilities among older adults, especially those with increased fall risk or cognitive impairment [60]. An additional support for using texting as a dual task is that it shows similar psychometric properties to other dual tasks. When opting to use texting as a dual task for locomotion, it is essential that researchers consider several key methodological points as described below.

4.1. Recommendations and implications for research

The papers presented in this review have revealed a number of methodological considerations that researchers need to address to ensure the value of their findings for future studies. Several of these considerations are general to all secondary tasks, such as calculating dual task cost for both tasks and reporting on task prioritization. The following section will highlight the recommendations which are unique to texting as a dual task.

Understanding the effect of texting on dual task performance is important given the increasingly common use of this task as both a research paradigm and as a daily life activity. Since texting requirements are multi-factorial, exploring the effects of texting on walking should be done using a multi-dimensional approach. Texting tasks show different levels of visual, cognitive and motor demands (Section 2) that depend on the characteristics of the task. It is therefore essential that task characteristics and performance be documented in terms of the load to each domain (visual, cognitive, motor) in order to better understand the interplay between those domains. For example, the visual demands of a texting task can be measured by computing the amount of time a user gazes at the screen (e.g. [30]). The cognitive demands may be directly measured using technologies such as NIRS (e.g. [32]) or EEG, while taking into account the technological limitations of such methods. Selection of the type of walking task (overground, treadmill, obstacle course, etc.) needs to consider the advantages and disadvantages of each method (Section 3.1). In the case of TeWW, in order to comply with the ecological nature of the task, as well as with many prior studies, the use of overground walking has a key advantage.

We have shown here that TeWW studies vary in their measurement of texting performance. When measuring texting performance, future studies should select a standardized measure of texting speed (we suggest characters per minute) in addition to measures of texting accuracy such as the absolute or relative number of errors. Texting accuracy should also include the type of errors performed, i.e., omission, commission, or content-related errors; typically this has not been reported.

When evaluating the dual task cost of texting on locomotion, interference of some factors should be taken into account. A critical factor is skill; since texting performance is highly influenced by skill level, it is essential that the latter be carefully documented. Texting skill is composed of a motor component (finger dexterity), familiarity with the task (frequency of using texting for communicating in daily life) and familiarity with the cell phone; it is expected that a user will be more comfortable texting on a cell phone similar to his personal device (and operating system). Thus, skill level needs to be documented by objectively measuring single task texting as well as via questionnaires regarding cell phone and texting usage and other standardized measures of dexterity (e.g., Nine Hole Peg Test [61]). In addition, personal characteristics may greatly affect task performance or even the ability to perform the task at all; a texting dual task for locomotion may not be feasible for some populations, such as people using a walker or a cane, or people with a significant sensory or vision impairment. Some of those characteristics may have different effects on performance than traditional dual tasks. For example, the need to alternately look at the phone's small screen and look up to avoid colliding with objects, may be of challenge for those who wear glasses only for near or far vision correction. These personal characteristics need to be carefully documented or incorporated into the study's exclusion criteria.

Finally, the main advantage of texting – its ecological validity, is also a drawback since study of an ecologically valid task is more complex in terms of its requirements and possible confounding variables. Texting tasks that are more ecologically valid (e.g., responding to commonly used text messages) may be more difficult to compare between individuals (e.g., due to the varying length of text messages) and may include emotional content that will affect people in different ways. In addition, such tasks are more likely to involve several cognitive and sensorimotor requirements such as relying on memory, switching between keyboards (e.g., Emojis, letters or symbols). Another aspect of ecological validity is using one's personal mobile device which may lead to an unstandardized research protocol. Finally, ambient environmental factors may influence the ability of the person to text while walking, especially when measuring performance in a real-world setting. Thus, we recommend that the environment be videotaped from the subject's point of view in order to document the amount of distractions (e.g., other people walking, obstacles).

To conclude, the body of evidence compiled in this review provides support for using TeWW as a paradigm that will impact on two main fields. The first is mobile user interface design, which focuses considerable effort on developing technological solutions to the problems of mobile-use distraction in everyday life. For example, walking patterns can be identified via mobile sensors and trigger a change in text size while walking [62] or even a complete locking of the screen [63] in order to avoid the hazardous behavior of texting and walking. The second field is cognitive neuroscience; texting as a dual task can further promote understanding of the cognitive, motor and visual requirements of gait. In the future it may even be used as an intervention to improve dual task abilities in certain populations. Given the increasing prevalence of cell phone use in the general public, research in these two fields may promote the feasibility and applicability of this type of task in different populations.

Conflict of interest statement

The authors declare that they have no conflicts of interest.

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